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FOUNDATIONS AND MACHINERY FIXING

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PREFACE

It has always appeared to the author that the subject of engine and machine foundations is a strangely neglected one so far as technical literature is concerned. Engineering text books treat of it in a cursory and wholly inadequate manner, and were it not for occasional articles in the technical press (particularly that of America) the subject as a whole might be said to have virtually no literature. Yet, it is admittedly one of consequence; sufficiently vital at times to call for the expert services of the most eminent of engineers. It is intimately associated with the important matter of vibration nuisance, and the general well-being of most machinery depends largely upon its foundation or the manner in which it is fixed.

For examples of satisfactory practice in the design of foundations there is a vast field to draw upon; but failing the possession of or access to carefully kept records of personal work, data of this kind are not very readily obtainable. To some extent practice appears to be standardized, but the author is unaware of any published figures of value relating to the proportions of foundations for engines and machines of various types, speeds and horse-powers, although such proportions differ very materially and are certainly of consequence. It is partly to supply the deficiency that this book has been written, and the figures given in the chapters dealing with design are representative and, practically speaking, average values. In the majority of cases they have been taken from actual installations and the remainder are based upon the recommendations of engine builders. To enhance

the practical usefulness of the book, costs and prices have been included wherever possible, but in view of fluctuations and the varying conditions which obtain in different localities they should for the most part be accepted with reserve and be looked upon merely as approximations.

The compilation of the tables and certain other parts of the book has necessitated the collection of a considerable amount of data, much of which has been drawn from articles descriptive of installations published in the British and foreign technical press. The author is also indebted to several firms and engineers in private practice who kindly assisted him with information, frequently of an exclusive character.

FRANCIS H. DAVIES.

LONDON,
June, 1912.

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CHAPTER I

THE FUNCTIONS OF FOUNDATIONS, NATURE OF SOILS AND PILING

THE functions of a foundation are two in number. Firstly, a bed must be provided which will permanently maintain the machinery firm and level with all its parts in true alignment. Secondly, it must be so constructed and proportioned that it will absorb shock and vibration so far as it is possible to do so. According to the class of machine and its location one or other of these considerations will assume primary importance. Thus, with a purely rotary machine such as a steam turbine or electric motor correct levelling and alignment are of more importance than the absorption of vibration, which in a well-balanced rotary engine of any kind should be almost entirely absent. This means lighter foundations than those which would be needed for a reciprocating engine or machine, the unbalanced parts of which set up vibration that can only be effectively damped by a heavy bed and possibly some special means in addition. Location must be taken into account because in certain situations even the smallest amount of vibration is prohibitive, whilst in others the only limit is that which the machine itself will stand without injury.

Design, so far as it affects engine or machine foundations is the duty of the engineer and comes within his scope; but when conditions of soil are such that the whole area under the works requires special treatment such as piling or the provision of a concrete

raft, the matter is rather one for the architect, since it affects the entire building. In such cases the engineer is concerned only with results, and details of design will be left to the architect who is dealing with a problem of which machine foundations form only a small and subsidiary part. As, however, co-operation between the two is usual and essential it will not be out of place to deal in a broad manner with the principles involved.

Bearing Power of Soils

The preliminary step in foundation design is thus determination of the quality of the soil. As is well known, soils differ materially in the weight per unit of area which may be safely placed upon them without risk of subsidence, and the subject is also intimately related to that of vibration and its transmission to surrounding property. It is of the utmost importance, and the success or failure of a foundation design may turn entirely upon it. There are numerous cases on record where the fatal error of over-estimating soil bearing power or of entirely neglecting it has been made, with the result that either the work has had to be done over again at great expense, or that the out of level conditions imposed upon the running plant by subsidence have been so onerous that its operation has been a continual source of trouble.

The following table gives the safe load per square foot in the case of various soils, the values given being taken from several authorities and representing usual building practice. As machinery is a moving load it is, however, best to err on the safe side and work to values somewhat less than the lower pressures given. If this be done there will be a considerable factor of safety which will be useful in the event of any error having been made in determination of the quality of the soil.

TABLE I

BEARING POWER OF SOILS

	Tons per sq. ft.
Alluvial soil and quicksand	$\frac{1}{2}$–1
Soft chalk	1
Soft moist clay	1–$1\frac{1}{2}$
Dry sand	1–2
Yellow clay	2
Very soft rock or sandstone	2
Ordinary gravel	3–4
London blue clay	4
Hard white chalk	4
Compact gravel	4–6
Dry clay in thick beds	4–6
Fine and compact sand	4–6
Firm sand not subject to lateral disturbance	8–10
Moderately hard rock	9
Hard rock in thick layers, up to	200

These figures tell part of the story, but when going into the question of soil there are other points to bear in mind than the maximum load it will carry.

Rock, for instance, will safely bear a very heavy load, but as a foundation for machinery it has its failings, chief among which is its power of transmitting vibration along a vein to a great distance. Several such cases have been known and have proved very difficult to rectify. In one within the author's personal knowledge four exactly similar vertical engines were installed, one of which happened to be placed upon a vein of bed rock. Three of the sets have never given cause for complaint, but the fourth, which was situated on the vein, was for a long time a continual source of trouble and expense, and it was only as a result of considerable structural alterations that an improvement was secured. The vibration set up by this engine was sensible all along the run of the vein to a great distance, and to such an extent that litigation was threatened by the property owners affected. The extreme rigidity of hard rock has before now been the cause of broken or loosened foundation bolts when the engine has been placed direct on the rock without

the intervention of a concrete bed. With the ordinary concrete block foundation a machine which owing to faulty construction tends to rock or vibrate badly probably finds a certain amount of relief in vibrating its foundation. That it does so is proved by the numerous instances where foundations have been split, and when built of brick or stone have fallen away in pieces. With hard rock there is no yield whatever, and under very arduous conditions of vibration it can only be a question of time for the foundation bolts to fail or for some other part to give out. In the ordinary course this is not a point to be feared or even anticipated, but it is of consequence where such conditions as the above obtain. To lessen the vibration which may be conveyed through a concrete foundation bedded on a vein of rock a layer of 5 in. or 6 in. of fine sand placed between the two has been found effectual. Rubber, paper and felt have also been used but they are more expensive and somewhat uncertain in their results.

A gravel soil is one of the best upon which to erect foundations of any sort. Not only has it ample bearing power but it is also dry and not given to subsidence from an extraneous cause. Sand, on the other hand, unless very dry and compact is treacherous, and in addition has a low bearing-power. It is particularly untrustworthy because any natural or artificial disturbance of the water level in the stratum, even at a great distance, may cause subsidence. Pumping or excavating operations in the vicinity may give rise to this, and a leaky drain by its eroding action has been known to cause trouble. Clay, also, is not to be trusted overmuch, particularly if it is at all wet. As the table shows, it varies materially in its bearing-power, and the same may be said of its nature generally. When compact and dry it will carry large loads, but it is essential to keep water away from it, both at the bottom and sides of the foundation, as subsidence may follow owing to the wet clay bulging up

around the structure. Made ground also cannot be trusted, even though it may have been undisturbed for years.

Preparation of Site

So far, we have dealt with certain specific soils, but it is a common experience to find a hard soil superimposed on a softer one and vice versa, and with these, good judgment is required to secure the best results. In the former case, the upper stratum will often carry a considerable load safely though the lower one is silt or even quicksand. It is hence not always desirable or necessary to pierce it, as the overlying hard soil floats as it were on the softer one, the pressure on the latter being distributed over a very wide area. Where the position is reversed and the softer soil is on the top the course to take depends upon its

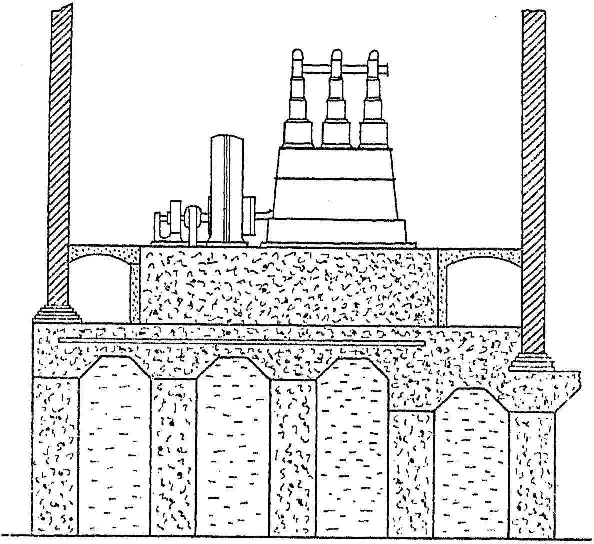


Fig. 1.—Concrete Wall Foundation.

depth. Should this not exceed 15 or 20 ft. it will generally be found cheapest to sink to firm ground. This was done in the case shown in Fig. 1, where borings disclosed the fact that the subsoil consisted of made ground, peat, clay and gravel, under which at a depth of approximately 22 ft. was found hard red marl. The soil on the whole was of an unstable nature, subject to alternate periods of dryness and wetness, and it was therefore decided to sink concrete walls as shown, varying from 4 ft. 6 in. in thickness upwards and running parallel with the walls of the building. A similar construction was carried out under the adjoining boiler house, the only difference being that the piers were spaced wider apart. An alternative to this method is the use of piles (either wood, iron or reinforced concrete) driven to the firm ground. Since in this case the piles act as columns and tend to bend under the load they should not be longer than 30 ft., and it is further necessary that they should have considerable sectional area. Piles which do not touch hard bottom but sustain the load simply by friction with the surrounding soil do not act as columns and may therefore be of smaller diameter. In the former instance the maximum safe load is usually taken as 1,000 lb. per square inch of head area, and in the latter 200 lb.

In situations where a hard bottom may be found at reasonable depth, heavy iron cylinders are often employed to carry the weight of the building. They are sunk into position by excavating the ground inside and letting them sink by their own weight or, if necessary, by loading with additional weight. As the cylinders sink, other lengths are bolted on by means of internal flanges, and when bottom is reached the interior is filled with concrete. The size of cylinder usually employed for this type of work varies from 4 ft. to 10 ft. in diameter and is cast solid in lengths of from 5 ft. to 10 ft. with a thickness of from 1 in. to $1\frac{1}{2}$ in. Occasionally brick or masonry cylin-

ders or wells are used, in which case the structure is built upon an iron or wooden foot serving the dual purpose of a base upon which to erect the work and a shoe to cut its way into the ground.

In Fig. 2 is shown an example of wood-piling in soft ground of considerable depth. In this particular

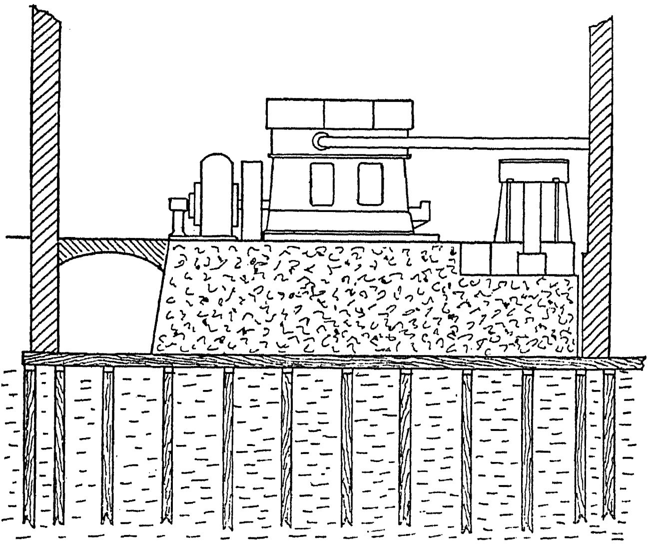


FIG. 2.—Foundation on Wooden Piles.

instance, which comes from Holland, the subsoil was very poor and unstable, necessitating a more than usually elaborate arrangement of piling over the entire site of the works. The piles employed were 46 ft. long by $9\frac{3}{4}$ in. diameter and were spaced regularly at intervals of 4 ft. 1 in. The load on each was estimated at 4 tons, which is reasonably within the abovementioned figure of 200 lb. per square inch of sectional area for a pile unsupported at its base. On the top

of the piles runners measuring $9\frac{3}{4}$ in. by $7\frac{7}{8}$ in. were carried the entire length of the building, supporting a floor as shown in the drawing. In cases of this nature where the soil is soft to a considerable depth, it is very usual to enclose the whole area of the works with sheet piling in order to consolidate the ground as much as possible. Timber sheet piles are generally made of battens 9 in. to 12 in. wide and 3 in. to 6 in. thick, the lower ends being shod with iron and bevelled in such a manner that the operation of driving forces them together and assists in making the joint as water-tight as possible (Fig. 5). It is also advisable in such cases to surround the heads of the piles to a depth of several feet with concrete, as this will obviate lateral yielding which is always apt to occur in very bad ground. Where the tops of the piles are connected by beams, substantial cross pieces measuring say 12 in. by 9 in. for 12 in. piles are affixed to the heads by means of notches. These run laterally across the whole area, and carry string pieces of similar size running longitudinally or at right angles to them. On the top of these latter a floor built of 3 in. to 4 in. planking is laid diagonally, and on this the masonry of the foundation is based. Old rails have been used as string pieces, and in view of the strength they give to the structure when embedded in the concrete are very suitable.

An alternative to piling which is useful where the soil though bad is not extremely so is to excavate the surface soil and fill in with carefully rammed sand kept in position laterally by sheet piling. The more usual proceeding, however, is to build a raft or platform of concrete which distributes the pressure over a wide area and is at the same time partially supported by friction between its sides and the surrounding soil. For this latter reason it is essential that such a platform should be thick, although not excessively so, as its weight would then tell against it to a more than commensurate extent,

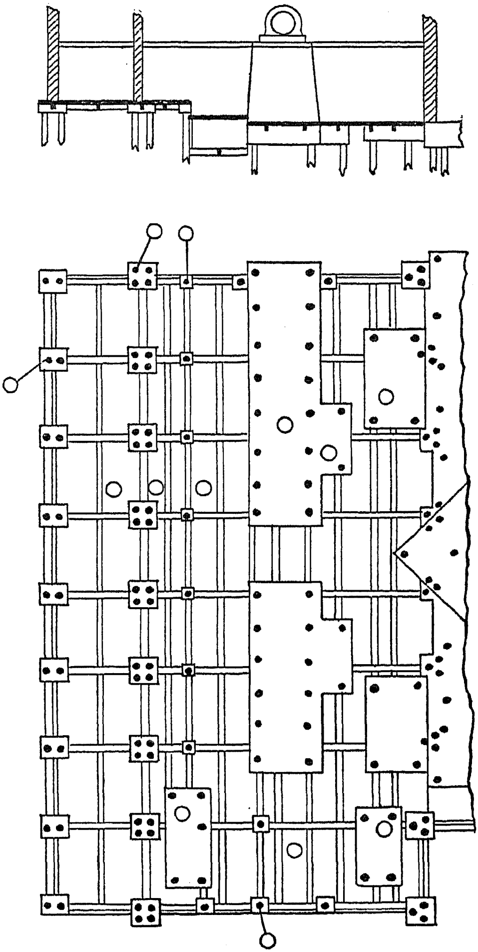


Fig. 3.—Foundations supported upon Concrete Raft and Piles.

A combination of piling and a concrete raft is shown in plan and elevation, Fig. 3. This construction was employed in the case of a large electric power station erected on soil which some twenty years previously had been reclaimed from a river. Over 300 ferro-concrete piles driven down to bed rock were used, and on these was constructed a concrete raft varying in thickness from 4 ft. to 4 ft. 6 in. The disposition of the piles is interesting. It will be noted that they are placed under all the piers of the building and are arranged more or less symmetrically under all the engine and turbine foundations. The construction is eminently sound and suited to meet the most unfavourable conditions.

The case of an American generating station situated at Portland, Ore., is interesting by reason of the very comprehensive methods necessitated by the bad quality of the soil. The station is situated on the banks of the Williamette River, and the soil is very unstable, containing a quicksand belt about 20 ft. to 30 ft. thick and from 50 ft. to 65 ft. below the floor of the works. To meet the difficulty, over 3,000 piles spaced at 3 ft. centres were employed, and many of these were spliced and driven to a depth of over 150 ft. The heads were then sawn level, and a 3 ft. concrete raft reinforced with 50 tons of $\frac{3}{4}$-in. steel bars worked up into a network was built on top. The foundations were further surrounded by 80,000 cubic yards of gravel, sand and loam carried up to the ground level in order to prevent lateral yielding of the quicksand, and at a later date the area thus enveloped was also sheet piled.

Piles

Either timber, iron or ferro-concrete may be used for piles, the latter having of late years greatly superseded the former for important work. The best woods for timber piles are oak, elm, beech, larch, teak,

pine and fir, of which the two latter are most frequently used. In diameter they vary from 9 in. to 18 in. according to the length. The lower end is pointed for a distance of from one and a half times to twice the diameter, and when driven in comparatively hard ground the end is fitted with an iron shoe having a solid point. In such cases the timber pile is left with a blunt end of from 4 in. to 6 in. in diameter which fits in the shoe. The upper end or head of the pile is encircled with a wrought-iron hoop about 3 in. deep by 1 in. in thickness, the function of this being to prevent splitting of the wood under the blows of the ram. This latter ranges in weight from 5 cwt. to 1 ton according to the quality of the ground and the diameter of the pile. Generally speaking, a heavy ram or monkey with a low fall is preferred as such a blow is less likely to injure the wood, but a light ram and a high fall is often employed for clay soil in particular. In the ordinary system of pile driving the ram is raised either by hand or power and then allowed to fall on to the head of the pile, being guided in its descent by two uprights forming part of the frame of the pile driver. In driving it is necessary to proceed until sufficient resistance is secured. This will vary with circumstances, but as a guide it may be mentioned that a common rule is to cease when as a result of thirty blows from a ram of 800 lbs. falling 5 ft. penetration does not exceed $\frac{1}{5}$ in. In another less used system the foot of the pile is fitted with a large screw, and the whole being rotated the latter bores its way into the ground. Such piles are constructed of wood, cast iron or wrought iron and are circular in shape with a diameter ranging between 6 in. and 18 in. The auger fixed to the foot of the pile makes about $1\frac{1}{2}$ turns of its circumference, and diameters up to 6ft. are used. Generally such piles are driven by manual power through the agency of a capstan at the head, and as the friction is considerable in hard ground a water jet is used to facilitate sinking.

There are several firms undertaking the construction of ferro-concrete piles and a good deal of experience has now been obtained with them. It was thought that no combination of concrete and steel would withstand the heavy blows of the pile driver, but there is now no question on that point and piles of this class up to 60 ft. in length are in use. Fig. 4 illustrates the construction of a 12 in. by 12 in. ferro-concrete pile on the well-known Hennibique system. Four circular steel rods of $1\frac{1}{2}$ in. diameter are placed in three-sided wooden boxes, their spacing being adjusted by gauges at a distance of 1 or 2 in. from the sides. It is desirable from the point of view of design that they should be near the surface, but there should be a protective coating of at least 1 in. or 2 in. of concrete. The rods are tied together as shown by $\frac{3}{16}$ in. or $\frac{1}{4}$ in. round wire, these ties being dropped over the ends of the rods and spaced at distances varying from 2 in. at the ends of the pile to 12 in. at the centre. Their function is that of preventing the rods from spreading apart under the influence of a vertical load. The concrete used is made of the best Portland cement only in the proportion of one part of cement, two parts of sand and four of stone. It is laid and packed with special small rammers about 6 in. at a time, and the fourth side of the box which is built up of battens fitting in grooves in the other sides is then put on. Piles are usually constructed in a vertical position, but the result is as good if the moulds be horizontal. The important point is that they should not be taken from their forms under four weeks at least, as in view of the shocks administered in driving it is essential that they should be thoroughly set.

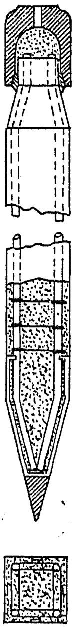


Fig. 4.—Section of Ferro-concrete Pile.

The section at the upper end of the pile (Fig. 4) is that of the driving cap which is of cast steel. It fits easily on the head of the pile which is made specially small to accommodate it, and the semi-circular space between the two is filled with sawdust or sand in order to cushion the blow of the ram. The lower end of the cap is packed with clay held in place with yarn. The rod armouring it will be noticed projects slightly from the head of the pile, and this forms a convenient method of fixing cross pieces to connect the heads together. The shoe in this class of pile consists of a chilled cast-iron point fixed by means of four wrought-iron side plates or straps locked in the concrete as shown.

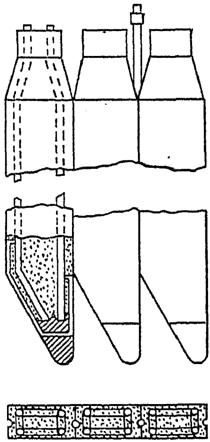


FIG. 5.—Ferro-concrete Sheet Piling.

In Fig. 5 is illustrated the Hennibique method of sheet piling. The general construction follows the lines of the above, but in order to form a joint between adjacent piles and to assist in securing a straight drive, a tongue and groove is arranged for between each pair. An alternative to this method is that shown, in which an iron pipe is laid in semicircular grooves in the sides of two adjacent piles. A stream of water at high pressure is delivered through this, and by its erosive action helps materially by clearing a way for the pile as it is being driven. At the end of the operation the pipe is taken out and the space filled in with cement. The safe working stress for ferro-concrete piles is between 350 and 550 lb., per square inch, and their total cost, including all material and labour, may be taken at 5*s*. 4*d*. per cubic foot. Driving costs about 2*s*. 6*d*. per foot run inclusive.

CHAPTER II

TRIAL BORES--DESIGN OF FOUNDATIONS

TRIAL BORES

IN many instances the nature of the subsoil will be well known, but if this is not the case, a trial pit must be sunk to a depth that will satisfactorily show the various strata. Alternatively, the subsoil may be examined by boring carried out by means of a large auger specially designed for the purpose. Its shank is built up of a great number of rods of moderate length, and during the operation of boring it is frequently pulled up in order that the nature of the lowest stratum may be ascertained. The auger brings with it a sample of the soil, and the depth of each stratum determined by this means is carefully noted. It is important to remember that boring should not be stopped when a suitably hard and good soil, such as gravel, is reached. It is very essential to know its depth, and therefore operations should be continued until the next stratum is reached or until the hard soil has been proved to be of sufficient depth. Where a trial boring is not to exceed a depth of 50 ft. from the surface or 6 in. diameter at the commencement, a well-borer will charge at the rate of two guineas per day with a minimum of one week. This price includes all supervision, labour and plant, but does not include any materials or tubes that may be necessary.

DESIGN

The quality of the soil being known, the first step in design is to determine the base area of the foundation,

its depth and its weight. It is very usual where the soil is normal to provide an area slightly larger than that of the bedplate and a depth that will carry the foundation down to a good footing below the frost line. The subject of weight is thus entirely ignored. The length of the holding-down bolts, which are probably supplied by the maker of the engine or machine, is also frequently accepted as a guide to depth, which may thus be arrived at in a purely arbitrary manner. Very often this procedure yields good results, but it cannot always be regarded as economical or quite safe, and in some instances it would certainly go astray. In the author's opinion foundations are often made unnecessarily heavy by reason of the designer relying upon rule of thumb methods and making sure of erring upon the right side. Equally certain is it that they have failed through lightness, and considerable expense has been incurred by neglect to check the dimensions of an arbitary design by accepted formulæ.

Base Area

Taking the simplest case, the base area naturally cannot be less than that of the machine bedplate or whatever other supporting surfaces are provided, but on certain soils and under abnormal conditions it may possibly have to be more. With the bearing-power of the particular bed and weight of the machinery known it is a simple matter to determine the margin left for weight of a foundation of a slightly larger area than that of the bedplate, and as stated this area will generally be found sufficient. Should this not be the case, one can proceed by a process of trial and error, adding area until it more than compensates for the weight of the additional concrete it involves. For the purpose the weight of concrete may be taken at an average figure of 150 lb. per cubic foot. The limits are generally assumed to be 120 lb. and 164 lb. per cubic foot respectively, the former applying to con-

crete made of ordinary natural cement and light furnace slag, and the latter where heavy Portland cement and limestone or trap rock is used. Where extra base area only is required and additional weight is not a consideration it is customary to build the foundation with a batter of, say, 1 in 8 or thereabout. This is a safe figure, but if the batter be too pronounced there is a tendency for the toe of the foundation to deflect upwards under the stress, or it may even crack off. The result of this would be to diminish the effective area appreciably, and it is therefore of importance that the batter should not be carried to an extravagant extent.

The bearing-power of soil is not necessarily the only consideration to influence base area. Owing to anticipated trouble with vibration it may be imperative to increase very largely the weight of a foundation, and where there is room this may best be done by increasing the area. The additional weight might be added by giving extra depth, but this course will not be so satisfactory and is moreover more expensive. Often a combination of the two is necessary for the reason that the possible area is restricted.

Distribution of Material

An important point to bear in mind where any reciprocating engine is to be installed is the correct distribution of the foundation with respect to the thrusts set up by the inertia of the moving parts. It will be best to take a concrete example, as in Fig. 6, which represents a single cylinder horizontal engine. In this class of engine the centre of gravity is behind the shaft, and the moving parts will set up a diagonal thrust more or less in the direction shown by the line. As illustrated, the foundation is so proportioned that the line of this thrust does not fall outside it, and this is correct practice that makes for a stable engine. But, if the foundation had been cut off at the dotted

line, the thrust line would have fallen well outside it, with the obvious consequence that stability would be affected to a degree varying with the height at which the thrust line left the foundation. It is impossible

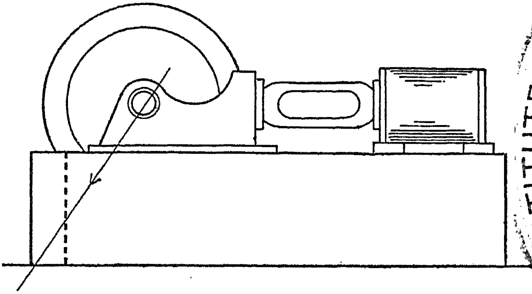


FIG. 6.—Approximate Position of Line of Thrust in Horizontal Engine.

to do more than indicate the principle and it must be left to the designer to think out the conditions of the particular case he is working on. The main conclusion to be drawn is that area should not be scamped in any direction along which it is possible for a thrust to travel. Probably a great deal of vibration trouble arises from this source which appears to be little appreciated if the average small engine foundation may be taken as a criterion.

DEPTH

The depth of a foundation is influenced primarily by the necessity for finding good bottom, but it is also affected by considerations of weight, length of holding-down bolts, and the depth to which frost may be expected to penetrate. This latter ranges from 3 ft. to 6 ft. according to climate, but in England it is customary to assume 3 ft. for ordinary soils and 4 ft. for clay. As regards bolt length, it is mentioned in the chapter on that subject that bolts should

have a length of at least thirty times their diameter, excepting where the machine to be fixed is of a light character. Frequently, however, a foundation must be much deeper than the bolt length indicates for the reasons that good bottom would probably not be found at that depth and that even if it were the weight of such a comparatively small mass of concrete would not give proper stability or be sufficient to absorb vibration. This brings us to the question of weight, about which there appears to be very little exact information or agreement of opinion.

Weight

The object of weight in a foundation is to absorb vibration, to prevent rocking or movement of any kind and to resist lateral pulls where, for instance, belt-driving is employed. Unfortunately very little is known about the subject, and a general rule cannot be laid down owing to the fact that almost every case will differ in some essential point. Thus, type of engine, whether vertical or horizontal, good or bad balance of the reciprocating parts, speed and angle of belt pull will enter into the question, which becomes further complicated when such opposites as reciprocating pumps and purely rotary electric motors or steam turbines are brought into it. It is only possible to say broadly that foundations as ordinarily laid down, have a weight of from one and a half to five times that of the machine or engine they support. These figures have been arrived at by examining a large number of designs and actual installations of all classes, and there can be no doubt that excluding very exceptional cases they represent the two extremes.

Although it is important that a certain minimum of weight should be provided, it must be remembered that with this exception the question is always subordinate to base area and depth which must primarily influence design. Speed will obviously have a very

great effect upon weight where belt or rope driving is used since the pull tending to displace the foundation will vary inversely and in proportion with the speed.

In the succeeding chapter an attempt has been made to put the important matter of weight on a firm basis. To arrive at the data given a large number of actual installations have been analysed, and of these the plants incorporated in the tables are perhaps most representative of average practice and results. It must be borne in mind, however, that comparisons such as these are limited in their application. It is impossible when each set of conditions requires special treatment to standardize practice, but it is feasible to make certain comparisons without attempting to establish anything in the nature of universal laws. It has been suggested more than once that it should be possible, for instance, to express the necessary weight of a foundation in terms of pounds per H.P., but this cannot be done with any degree of accuracy unless the class of engine is taken into account. This is the dominating factor, but in each class of engine speed and depth to good bottom have also an important bearing. All we can do, therefore, is to segregate machinery into classes, select normal speeds, and an average depth of foundation. We can then obtain approximate data as to weight of foundation in pounds per H.P. which will be useful in checking design.

The tables in the following chapter give the base area in each case, but the figures relating to the total pressure in tons per square foot on the subsoil are of more importance. It will be noted that this is in most instances, comparatively low, which fact tends to show that where prime movers generally, electric generating plant and electric motors are concerned, an area slightly in excess of that of the bedplate is in all but abnormal cases a safe one. The majority of these plants might have been erected with impunity upon all but the worst of soils, as in no case does the

area at the foot of the foundation very much exceed that of the bedplate and a normal margin. It is thus clear that so far as machinery of this description is concerned (with the exception of the electric motor, and to some extent the gas engine), the average pressure upon the subsoil is in the neighbourhood of from $\frac{1}{2}$ to $1\frac{1}{2}$ tons per square foot. Higher or lower values, if not exactly abnormal, are unusual. For instance, the machinery in Case 3, Table IV, was particularly heavy and the foundation deeper than the normal; hence a pressure on the subsoil of 1·25 ton per square foot. The pressure is also generally high in the case of turbo-generators which are commonly placed upon two separate blocks of comparatively small base area. On the other hand, the electric motor, being at average speeds a light machine for its output, gives a pressure on the subsoil well under ·5 ton per square foot even when its foundation is more than usually heavy. These and other points, as they affect each class of engine, are dealt with in the succeeding chapter.

CHAPTER III

DESIGN—THE PROPORTIONS OF FOUNDATIONS FOR ENGINES, TURBINES AND DYNAMO ELECTRIC MACHINERY

Vertical Enclosed Steam Engines

The seventeen instances given in Table II under this heading, show that on the whole the weight of foundation per H.P. falls off as the power of the engine increases, and judging from well-established practice the range is from 150 lb. to 350 lb. per B.H.P. according to the output and weight of the engine and the depth of the foundation. The proportion of foundation and engine weights is in the neighbourhood of 2 or 3 to 1, and assuming that an area approximately equal to that of the bedplate will suffice and that the soil is good, it will only be necessary for the designer to arrange for such a depth as will give the requisite weight proportions.

As regards the instances given in the table. No. 4 has an unusually heavy foundation and its weight per B.H.P. is high. The engine was equipped with an extension bed, extra bearing and pulley for belt drive, which materially increased the length and therefore weight of the foundation. No. 7 is a comparatively light engine for its output, but its foundation is deep; hence, an unusual weight proportion of 4·3 to 1. The remaining instances call for no special remark as their proportions and weights are normal, but the falling off in proportionate weights and

TABLE II

VERTICAL ENCLOSED STEAM ENGINE FOUNDATIONS

No.	Engine. Description.	Engine. Weight. Lbs.	Foundation. Weight. Lbs.	Foundation. Weight. Lbs. per B.H.P.	Foundation. Base Area Sq. Ft.	Foundation. Depth Ft.	Proportion of Foundation and Engine Weights.	Total pressure per Sq. Ft. on soil. Tons.
1	70 B.H.P., compound, 600 r.p.m. . .	6,130	22,500	321	30	5	3·6 to 1	·42
2	100 ,, ,, 525 ,, . .	7,280	22,500	225	30	5	3·1 to 1	·44
3	130 ,, ,, 500 ,, . .	12,320	37,800	290	42	6	3 to 1	·53
4	150 ,, ,, 380 ,, . .	20,160	70,875	472	105	4·5	3·5 to 1	·39
5	200 ,, ,, 435 ,, . .	15,680	43,200	216	48	6	2·7 to 1	·54
6	250 ,, ,, 375 ,, . .	21,840	56,700	226	63	6	2·6 to 1	·55
7	300 ,, ,, 350 ,, . .	22,400	96,000	320	80	8	4·3 to 1	·66
8	400 ,, ,, 375 ,, . .	28,224	73,500	184	70	7	2·6 to 1	·65
9	400 ,, triple 375 ,, . .	38,976	102,900	257	98	7	2·6 to 1	·64
10	500 ,, ,, 360 ,, . .	44,800	126,000	252	130	6	2·7 to 1	·58
11	530 ,, compound 375 ,, . .	32,480	80,850	152	77	7	2·4 to 1	·65
12	530 ,, triple 375 ,, . .	51,856	110,250	208	105	7	2·1 to 1	·68
13	650 ,, ,, 333 ,, . .	65,184	134,400	206	128	7	2 to 1	·69
14	1,000 ,, ,, 250 ,, . .	110,320	216,000	216	180	8	1·9 to 1	·80
15	1,100 ,, ,, 224 ,, . .	100,800	267,300	243	198	9	2·6 to 1	·82
16	1,300 ,, ,, 250 ,, . .	153,104	237,600	182	198	8	1·5 to 1	·88
17	2,000 ,, ,, 188 ,, . .	246,400	336,000	168	280	8	1·3 to 1	·92

TABLE III

FOUNDATIONS FOR VERTICAL ENCLOSED STEAM ENGINES DIRECT COUPLED TO GENERATORS

No.	Engine and Generator.		Foundation.				Proportion of Foundation and Engine, etc., Weights.	Total pressure per Sq. Ft. on soil Tons.
	Description.	Weight. Lbs.	Weight. Lbs.	Weight. Lbs. per B.H.P.	Base Area Sq. ft.	Depth Ft.		
1	300 B.H.P., compound, 350 r.p.m., and 240 KW. generator	58,240	240,000	400	200	8	4·1 to 1	·66
2	430 B.H.P., compound, 375 r.p.m., and 300 KW. generator (also pump engine) .	107,520	360,000	409	300	8	3·3 to 1	·69
3	475 B.H.P., triple, 300 r.p.m., and . . . 330 KW. generator	96,320	363,600	382	303	8	3·5 to 1	·67
4	500 B.H.P., triple, 360 r.p.m., and 350 KW. generator	78,200	180,000	180	200	6	2·3 to 1	·57
5	1,100 B.H.P., triple, 230 r.p.m., and 800 KW. generator	156,800	604,800	275	504	8	3·8 to 1	·67

weight per B.H.P. is very marked as the largest sizes are reached.

It will be noticed from the five examples in Table III that the direct coupling of an electric generator to engines of this class does not materially alter proportions, the pounds of foundation per B.H.P. and the relative weights remaining on the average about the same. In this connexion it should be noted that in determining the pounds per B.H.P. the latter value is doubled, so as to take into account the total H.P. of machinery supported by the foundation.

There is little to be said regarding the form or shape of foundations for this type of machinery. In practically all cases it consists of a simple block, either isolated or embedded in the soil. In shape it may follow the principal lines of the machinery with the usual margin all round, or the block may be simply of a plain cubic form with horizontal dimensions rather greater than the maximum length and breadth of the plant. In electric power stations and other industrial plants where two or more machines are placed close together it is a usual practice to mount the several units on one common block of concrete, the bulkiness of which is one of the best guarantees against vibration trouble or settlement. With a view to preventing the spread of vibration, such a block is kept clear of the walls of the building, as all foundations should be. At times this method is varied in the manner shown in Fig. 7, which represents a typical foundation lay-out for three adjacent 1,000 KW. generating sets. The arrangement is a good one and allows condensing plant to be placed in the pits between the engines. From the point of view of vibration absorption it cannot be quite so effective as a solid block of regular shape since it is very much lighter, but in all but exceptional cases it would be satisfactory. The distance between centres of engines thus placed in a row, whether on a joint or separate beds, is a matter which local conditions control. It

would be hardly worth mentioning but for the fact that in seeking to economize space some designers go

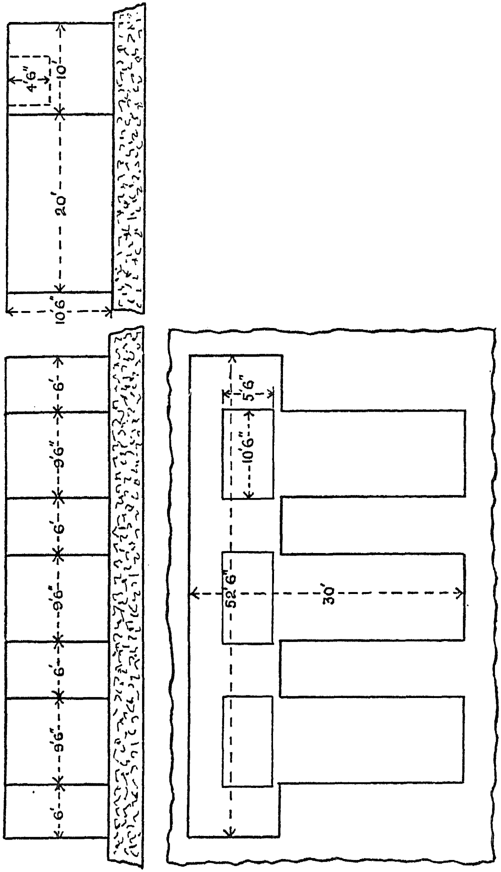


FIG. 7.—Lay-out of Foundation for 3–1000 KW. Direct Coupled Generating Sets.

too far in the direction of compactness and leave insufficient room for dismantling. It is sometimes

TABLE IV

FOUNDATIONS FOR VERTICAL CROSS-COMPOUND STEAM ENGINES DIRECT COUPLED TO GENERATORS.

No.	Engine and Generator.		Foundation.				Proportion of Foundation and Engine, etc. Weights.	Total pressure per Sq. Ft. on soil. Tons.
	Description.	Weight. Lbs.	Weight.		Base Area Sq. ft.	Depth Ft.		
			Lbs.	Lbs. per B.H.P.				
1	700 B.H.P., 90 r.p.m., and 2–250 KW. generators	335,000	642,600	459	576	8·5	1·9 to 1	·75
2	1,100 B.H.P., 100 r.p.m., and 800 KW. generator	385,000	843,600	383	532	12	2·1 to 1	1·03
3	2,000 B.H.P., 80 r.p.m., and 1,500 KW. generator	617,980	1,996,800	499	932	18	2·7 to 1	1·25

forgotten that although the floor space between the engines is ample for this purpose, it may be more or less congested with pipes, particularly if the exhaust main is located in a floor trench.

Vertical Cross-compound Steam Engines Direct Coupled to Generators

Owing to its greater weight per unit of output the weight of foundation per B.H.P. is rather higher with this class of plant than with the foregoing. A fair average figure for a combined set is 450 lb. per B.H.P., and the proportionate weights of foundation and machines may be said to range from 1·5 to 1 to 3 to 1. The pressure per square foot on the subsoil is higher than in any other class of engine, a result one would naturally expect since the plant is heavy, but at the same time does not occupy a great area.

The examples given in Table IV are typical of the class and its variants. In the case of No. 1 it will be noticed that the engine was coupled to two generators, which accounts for the fact that the base area was high and the pressure per square foot on the subsoil comparatively low. This also explains the rather exceptional weight of the machinery. Nos. 2 and 3 call for no remark as with the previously noted exception in the case of the latter they are typical of the average.

Horizontal Steam Engines

It is well known that horizontal engines require greater floor space for a given H.P. than any other type. This increases the weight of foundation per B.H.P., which commonly ranges between 500 lb. and 1,000 lb. per B.H.P.

The proportion of foundation to engine weights in this class is higher than in any other, being in the neighbourhood of 4 to 1. The cross compound type

TABLE V

FOUNDATIONS FOR HORIZONTAL STEAM ENGINES

No.	Engine.		Foundation.				Proportion of Foundation and Engine Weights.	Total pressure per Sq. ft. on soil Tons.
	Description.	Weight. Lbs.	Weight. Lbs.	Weight. Lbs. per B.H.P.	Base Area Sq. ft.	Depth Ft.		
1	100 B.H.P., tandem compound, 245 r.p.m..	14,400	57,750	577	77	5	4·1 to 1	·41
2	350 ,, ,, ,, 195 ,, .	46,750	198,000	565	220	6	4·2 to 1	·49
3	450 ,, double crank compound, 175 r.p.m.	63,500	302,400	672	288	7	4·7 to 1	·56
4	1,200 B.H.P., cross compound, 100 r.p.m. .	339,000	1,276,800	1,064	792	11	3·7 to 1	·91
5	2,250 ,, ,, ,, 75 ,, .	680,000	2,435,400	1,082	1,353	12	3·5 to 1	1·02

TABLE VI

Foundations for Horizontal Steam Engines Direct Coupled to Generators

Engine and Generator.		Foundation.				Proportion of Foundation and Engine, etc., Weights.	Total pressure per Sq. Ft. on soil Tons.
Description.	Weight. Lbs.	Weight. Lbs.	Weight. Lbs. per B.H.P.	Base Area Sq. ft.	Depth Ft.		
550 B.H.P., cross-compound, 100 r.p.m., and 400 KW. generator.	185,000	679,050	617	503	9	3·6 to 1	·76
550 B.H.P., cross-compound, 100 r.p.m., and 400 KW. generator	268,000	799,200	726	444	12	2·9 to 1	1·07
700 B.H.P., cross-compound, 83 r.p.m., and 2,000 KW. generator	851,200	2,466,000	456	1,280	12	2·8 to 1	1·15

occupies a proportionately greater space than either the tandem or the two crank, and hence it will be noticed that the weight of foundation per B.H.P. is greater, as is also the pressure on the subsoil owing to the larger mass of concrete.

The addition of a direct connected electric generator

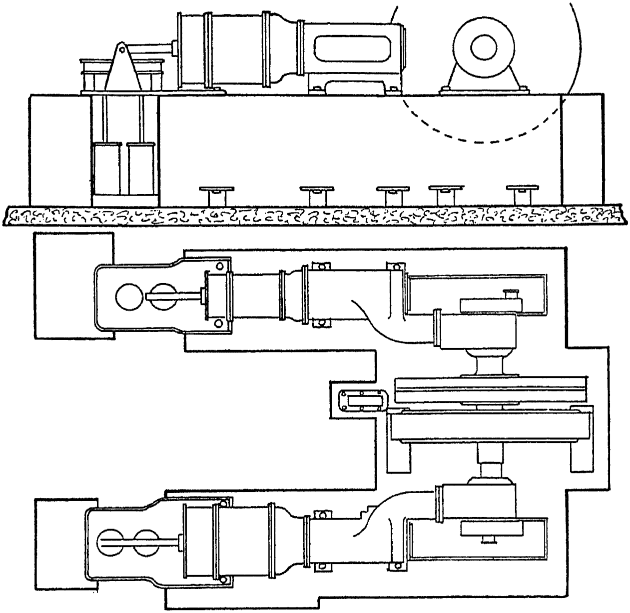


FIG. 8.—Foundation Lay-out for 2,700 B.H.P. Horizontal Cross-compound Engine and 2,000 K.W. Generator.

to a cross compound horizontal engine (Table VI) makes comparatively little difference to the foundation area or its weight; hence the proportion of the two weights only drops slightly, while the weight per B.H.P. of combined plant falls considerably. Further, as the base area will be but slightly increased the

pressure per square foot on the subsoil rises. Example No. 1 is normal, but in the case of No. 2 the plant was of a heavy class and the foundation was deeper. When dealing with this type of engine it should be remembered that there is often a great difference in the flywheel weight for engines of equal power, especially where the comparison is between units designed for a lighting and traction load respectively. Examples Nos. 1 and 2 afford a case in point, the latter engine being heavier in all its proportions.

The foundation lay-out illustrated in Fig. 8 is that of a 2,700 B.H.P. horizontal cross compound engine coupled to a 2,000 KW. generator, and on broad lines is representative of the class. Particulars of the set are given in Table VI, No. 3 example. In this engine the air pumps are operated from tail rods, and it will be noticed that an independent block of concrete is provided at each cylinder end to support part of the gear. As the entire foundation rests upon a concrete raft there is no objection to this method, but small isolated blocks of this sort sunk direct in the soil should always be avoided as they are practically certain to settle and throw the parts they support out of alignment. This actually happened in the case of a horizontal pumping engine, which came under the author's notice. By an oversight or lamentable lack of knowledge the main bearings carrying a heavy flywheel were supported on a separate foundation to that of the rest of the engine. The soil was treacherous, and in course of time the bearings and cylinder got badly out of line with the result that the cylindrical crosshead guide cracked at the bolts.

Horizontal Steam Turbines Coupled to Generators

Salient points of the steam turbine are its comparative lightness, compactness and the absence of all horizontal or vertical thrusts tending to set up vibra-

tion. These features have necessarily a very marked influence upon its foundations, and it is well known that the steam turbine requires very little in this respect. Under the most favourable conditions it would only be necessary to consider the weight of the set and to provide a suitable weight and area of foundation. It will, however, be noticed that in practice turbine foundations are often very heavy and deep, the reason of course being the necessity for finding good bottom or for some structural cause connected with the building. It is also common practice to house condensing plant underneath the turbine, and if this be an essential point in the lay-out, the foundation

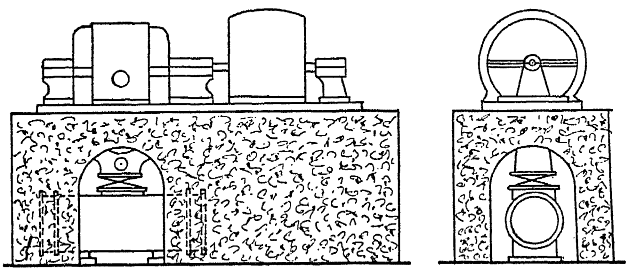


FIG. 9.—Foundation for Turbo-generator.

block, if employed at all, must necessarily be deep irrespective of the need for a firm base soil. A very typical arrangement is shown in Fig. 9, where, owing to a poor surface soil and the necessity for placing the condensing plant under the turbine, the foundation was comparatively massive and far heavier than was needful for stability only. There are numerous instances of which Fig. 10 is typical of turbines being placed on galleries or hollow floors. In this case the turbine is bolted down to strong girders running at right angles to and underneath those of the floor. The practice is apt to give rise to vibration trouble and to accentuate whatever slight disturbances may originate from

the turbine, but with this exception it is a perfectly feasible one.

Referring to Table VII, it will be seen that the foundation weight per B.H.P. of turbo-generator units is very low, although in all the three instances given the foundations were of a good depth. The area is correspondingly small, and the proportionate weights of the turbo-generator and its foundation are about the normal. The pressure per square foot on the soil is in each case high, the reason lying in the fact that the whole weight is concentrated on two or more blocks of small base area, and not, as in the ordinary

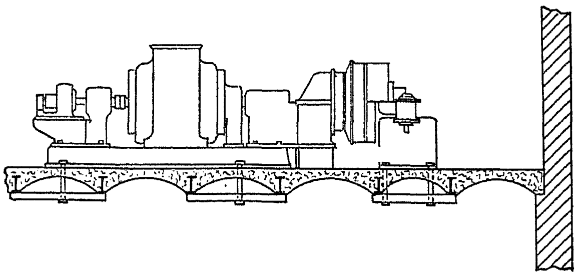


FIG. 10.—Method of Holding Down Turbo-generator to Hollow Floor.

reciprocating engine installation, spread over a block of the same area as the bedplate. Such figures as the above do not, however, carry much weight in the case of steam turbines because, as before stated, heavy foundations are installed not so much in the interests of stability and freedom from vibration as for structural reasons connected with the lay-out of the plant. This statement is applicable to the ordinary normal case, but there are of course instances where a good heavy bed is a necessity. Vibration is more common with small turbines than with those of larger sizes owing to the greater difficulty that is experienced in balancing the rotating elements. Where this is feared

TABLE VII

Foundations for Horizontal Steam Turbines Direct Coupled to Generators

No.	Turbine and Generator.		Foundation.				Proportion of Foundation and Turbine, etc. Weights.	Total pressure per Sq. ft. on soil Tons.
	Description.	Weight. Lbs.	Weight.		Base Area Sq. ft.	Depth Ft.		
			Lbs.	Lbs. per B.H.P.				
1	1,500 KW., 1,500 r.p.m.	134,400	513,000	127	285	12	3·8 to 1	1·01
2	5,000 ,, 750 ,,	358,400	1,075,200	80	476	16	3 to 1	1·34
3	6,000 ,, 1,000 ,,	355,040	1,102,500	68	350	21	3·1 to 1	1·85

it is best to provide a foundation that extends the whole length of the bedplate in place of the more usual practice of a block under the turbine and another under the generator with the intermediate space used for housing condensing plant.

Horizontal Gas Engines

Gas engine foundation practice, particularly that of horizontal engines, appears to be variable, and the recommendations of engine builders differ somewhat in the matter of depth and, therefore, weight. Area is of course fixed, or at any rate largely influenced, by the design of the engine, and here, too, for an equal H.P. there is much divergence. Reading between the lines it would appear that some builders have more trouble with shock and vibration than others, and therefore recommend a greater foundation bulk. Since there is so much divergence in practice it is not an easy matter to give instances which may truly be called typical, and it is necessary to avoid invidious comparisons which, in the absence of a full and thorough investigation of the principles upon which design has been based and the conditions of operation might tend to give an entirely wrong impression. On the whole, it is clear that the problem of gas engine foundation design is a very different one to that of the steam engine. For an equal H.P. the former engine is more likely to set up vibration, and it also requires a greater floor space and is heavier per unit of output. Further, a great proportion of horizontal gas engines are of the single cylinder, or at any rate the single line type, and are therefore really not comparable to steam engines which for the most part operate under entirely different conditions. The most marked divergence from steam engine practice is found in single cylinder horizontal gas engines of small size, and this conclusion is the result of analysis of a large number of cases. In engines of this class ranging from $2\frac{1}{2}$ B.H.P. up to

15 or 20 B.H.P., the foundations are sometimes lighter than or of about the same weight as the engine, and at first sight these proportions would appear to be eminently undesirable in the case of a prime mover particularly liable to set up vibration. However, it must be remembered that the weight per H.P. of gas engines is high, especially in the smaller sizes, and this weightiness assists stability by absorbing vibration and shock in the same manner as a foundation. As greater horse powers are reached conditions alter, and the weight of engine per B.H.P. falls and the proportion of foundation to engine weights rises. It has been thought unnecessary to include tabulated data of small horizontal gas engine foundations as practice appears to differ so widely that representative figures cannot be given. No doubt with these engines considerations of convenience and expense often outweigh all others. It is fairly evident that as a rule the matter is not thought out, and the proportions of the foundation are guessed at or settled in a purely arbitrary manner. No other explanation can be found for variations of as much as 100 per cent. in similar cases. One frequently hears of vibration troubles with small gas engines, and it is probable that this casual method of foundation design is often responsible. Some gas engine builders or their salesmen are chary of advising a good heavy foundation because of the inference which will naturally be drawn, particularly by the layman, and the severity of competition creates a tendency on the part of irresponsible salesmen to deprecate the need for heavy foundations because of the fear that in this respect their engine may compare unfavourably with those of competitors. However, when one comes to the larger sizes this doubtful form of business acumen is more or less absent and we reach firmer ground.

The data relating to the foundations of larger engines given in Table VIII, may be taken as conservative; that is to say, the weights and proportions are

TABLE VIII

Foundations for Horizontal Gas Engines

No.	Engine.		Foundation.				Proportion of Foundation and Engine Weights.	Total pressure per Sq. Ft. on soil. Tons.
	Description.	Weight. Lbs.	Weight. Lbs.	Weight. Lbs. per B.H.P.	Base Area Sq. ft.	Depth Ft.		
1	20 B.H.P., single cylinder, 4 cycle, 250 r.p.m.	10,640	30,000	1,500	50	4	2·8 to 1	·36
2	33 ,, ,, ,, 4 ,, 220 ,,	16,016	39,150	1,186	58	4·5	2·4 to 1	·42
3	42 ,, ,, ,, 4 ,, 210 ,,	17,360	46,500	1,107	62	5	2·6 to 1	·46
4	60 ,, ,, ,, 4 ,, 210 ,,	22,500	56,250	937	75	5	2·5 to 1	·35
5	85 ,, ,, ,, 4 ,, 190 ,,	28,000	81,000	953	140	6	2·8 to 1	·34
6	100 ,, ,, ,, 4 ,, 180 ,,	34,720	98,982	989	161	6·5	2·8 to 1	·36
7	125 ,, ,, ,, 4 ,, 170 ,,	42,560	118,314	946	185	6·75	2·7 to 1	·38
8	150 ,, ,, ,, 4 ,, 160 ,,	52,080	128,248	854	194	7	2·4 to 1	·41
9	170 ,, two ,, 4 ,, 190 ,,	50,960	156,750	922	183	6	3·07 to 1	·50
10	200 ,, ,, ,, 4 ,, 180 ,,	59,360	213,750	1,068	229	6·5	3·6 to 1	·53
11	250 ,, ,, ,, 4 ,, 170 ,,	73,920	248,400	993	256	6·75	3·3 to 1	·56
12	300 ,, ,, ,, 4 ,, 160 ,,	89,040	305,250	1,017	306	7	3·4 to 1	·57
13	375 ,, four ,, 4 ,, 170 ,,	117,600	310,500	828	357	6	2·6 to 1	·53
14	400 ,, single ,, 2 ,, 100 ,,	143,000	594,000	1,485	396	10	4·1 to 1	·83
15	450 ,, four ,, 4 ,, 160 ,,	147,840	371,250	825	387	6·5	2·5 to 1	·59
16	550 ,, ,, ,, 4 ,, 150 ,,	178,080	477,750	868	480	6·75	2·6 to 1	·61
17	650 ,, ,, ,, 4 ,, 145 ,,	196,000	529,500	814	512	7	2·7 to 1	·63

ample and safe. In cases 5 to 8, a pulley and extra bearing, as in Fig 11, are allowed for, thus making the foundation rather heavier than is strictly necessary from the point of view of stability. The B.H.P. is that which would be developed on producer gas of about 140 B.Th.U. per cubic foot, but with gas of comparatively high calorific value, such as town or

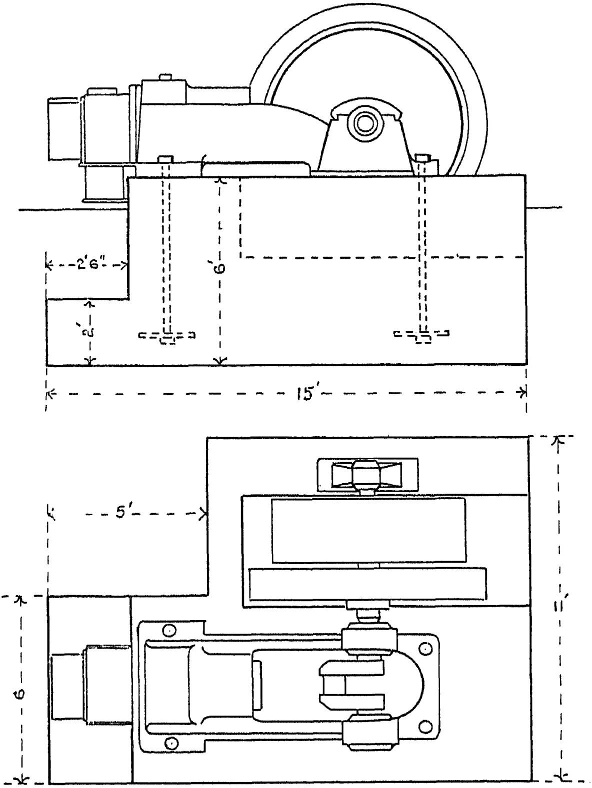


FIG. 11.—Foundation Lay-out for Horizontal Gas Engine.

coke oven gas, approximately 15 per cent. more power should be credited to the engines. The pounds of foundation per B.H.P. are on the average higher than in any class of steam engine, the horizontal type approaching nearest. The proportions of the foundation and engine weights as compared with steam practice are about normal, but the pressures on the subsoil are low, owing to the weight being spread over a greater area than in the case of a steam engine of equal H.P. The drawing Fig. 11 shows the usual type of foundation employed for single cylinder horizontal engines of this class, the dimensions applying to an engine of 85 B.H.P. or thereabout fitted with an extra bearing and pulley on an extended shaft.

Vertical Gas Engines

This type of engine is in every way more comparable to the steam engine than the horizontal. The weight of foundation per B.H.P. ranges from 400 to 500 lb., and the proportion of foundation and engine weights is slightly in excess of 2 to 1. The area occupied is considerably less than in the case of the horizontal gas engine, and hence the pressure on the subsoil rises to a comparatively high figure. It will be noticed that the depth of foundation advised is on the whole greater than is usual with vertical steam engines of similar output, particularly as the higher powers are approached (Table X). As will be seen from Table X the chief effect of direct coupling to an electric generator is to raise the proportion of foundation to plant weight and to reduce slightly the pressure per square foot on the subsoil. Both these effects are the natural outcome of the addition of a machine which compared with the engine is light but at the same time occupies a fair amount of floor space.

Vertical Diesel Engines

The important position which the Diesel engine is

TABLE IX

FOUNDATIONS FOR VERTICAL GAS ENGINES

No.	Engine.		Foundation.				Proportion of Foundation and Engine Weights.	Tota pressure per Sq. Ft. on soil. Tons.
	Description.	Weight. Lbs.	Weight.		Base Area Sq. Ft.	Depth Ft.		
			Lbs.	Lbs. per B.H.P.				
1	100 B.H.P., 4 cylinder, 2 crank, 325 r.p.m.	21,011	45,000	450	50	6	2·1 to 1	·58
2	150 ,, 6 ,, 3 ,, 325 ,,	30,016	64,500	432	72	6	2·1 to 1	·58
3	225 ,, 4 ,, 2 ,, 300 ,,	44,800	115,200	511	96	8	2·5 to 1	·74
4	335 ,, 6 ,, 3 ,, 300 ,,	62,720	134,400	401	112	8	2·1 to 1	·78
5	460 ,, 4 ,, 2 ,, 200 ,,	97,888	240,000	521	160	10	2·4 to 1	·94
6	690 ,, 6 ,, 3 ,, 200 ,,	140,000	300,000	434	200	10	2·1 to 1	·98
7	915 ,, 8 ,, 4 ,, 200 ,,	176,960	360,000	393	240	10	2 to 1	1·00

assuming in the field of power production makes separate treatment desirable. Figures relating to the foundations of a complete line of these engines are given in Tables XI and XII, and it should be noted that the depths specified are those advised as a minimum by the Diesel Engine Co., Ltd. On the whole, the essential features are very similar to those of the vertical gas engine, particularly where the foundation depths are about equal. The weight of foundation per B.H.P. is high compared with any class of steam engine, ranging between 400 and 800 lb., while the proportion of the foundation and engine weights is lower on the average. Subsoil pressures are about normal.

When coupled to electric generators the lb. per B.H.P. fall materially as shown in Table XII and the weight of the foundation tends to rise in proportion to that of the machinery.

Electric Generators and Motors

If belt or gear driving of any kind be employed, foundations are necessary unless the machine can be fixed rigidly to a stable body such as the floor or framework of a building. This latter class of fixing is fully dealt with in Chapter X, and we are here only concerned with cases comparable to that of an engine, where the machine (dynamo or motor) has to be placed on a concrete bed sunk or partly sunk in the soil. As a well-designed dynamo-electric machine seldom gives rise to vibration the function of the foundation in this case is principally that of affording stability and power to resist the lateral or vertical pull of the belt, as the case may be, without yielding. Similarly to engines, the two points of importance are weight of foundation per B.H.P. and proportionate weight of foundation and machine. Either will give an indication of the total weight of foundation necessary, but if both be calculated the one acts as a

TABLE X

Foundations for Vertical Gas Engines Direct Coupled to Generators

No.	Engine and Generator.		Foundation.					Proportion of Foundation and Engine, etc., Weights.	Total pressure per Sq. Ft. on soil Tons.
	Description.	Weight. Lbs.	Weight.		Base Area Sq. ft.	Depth Ft.			
			Lbs.	Lbs. per B.H.P.					
1	100 B.P.H., 325 r.p.m., and 65 KW. generator	30,401	100,800	504	112	6		3·3 to 1	·51
2	150 ,, 325 ,, ,, 75 ,, ,,	39,923	136,800	456	152	6		3·4 to 1	·51
3	225 ,, 300 ,, ,, 155 ,, ,,	60,085	205,200	456	171	8		3·4 to 1	·69
4	335 ,, 300 ,, ,, 230 ,, ,,	90,986	237,600	354	198	8		2·6 to 1	·73
5	460 ,, 200 ,, ,, 315 ,, ,,	131,779	429,000	466	286	10		3·2 to 1	·87
6	690 ,, 200 ,, ,, 475 ,, ,,	178,185	652,500	472	435	10		3·6 to 1	·85
7	915 ,, 200 ,, ,, 635 ,, ,,	238,460	816,000	445	544	10		3·4 to 1	·86

TABLE XI

Foundations for Vertical Diesel Engines

No.	Engine.		Foundation.				Proportion of Foundation and Engine Weigh ts	Total pressure per Sq. Ft. on soil. Tons.
	Description.	Weight. Lbs.	Weight.		Base Area Sq. ft.	Depth Ft.		
			Lbs.	Lbs. per B.H.P.				
1	30 B.H.P., 400 r.p.m.	11,200	20,106	670	22	6	1·8 to 1	·63
2	65 ,, 300 ,, ...	29,120	51,525	792	68	5	1·7 to 1	·45
3	130 ,, 300 ,, ...	40,320	85,740	659	98	5′ 10″	2·1 to 1	·57
4	200 ,, 300 ,, ...	51,520	106,200	531	118	6	2·1 to 1	·69
5	300 ,, 275 ,, ...	82,880	136,500	455	140	6′ 6″	1·6 to 1	·70
6	400 ,, 275 ,, ...	98,560	176,400	441	168	7	1·7 to 1	·72
7	600 ,, 220 ,, ...	188,160	363,000	605	242	10	1·9 to 1	1·01
8	800 ,, 220 ,, ...	224,000	429,000	536	286	10	1·9 to 1	1·01
9	1,000 ,, 215 ,, ...	268,800	648,000	648	360	12	2·4 to 1	1·13

TABLE XII

FOUNDATIONS FOR VERTICAL DIESEL ENGINES DIRECT COUPLED TO GENERATORS

No.	Engine and Generator.		Foundation.				Proportion of Foundation and Engines, etc. Weights.	Total pressure per Sq. Ft. on soil Lbs.
	Description.	Weight. Lbs.	Weight.		Base Area Sq. Ft.	Depth Ft.		
			Lbs.	Lbs. per B.H.P.				
1	30 B.H.P., 400 r.p.m., & 20 KW. generator	14,290	32,120	552	37	6	2·3 to 1	·56
2	65 ,, 300 ,, 45 ,, ,,	33,908	90,000	692	120	5	2·6 to 1	·46
3	130 ,, 300 ,, 85 ,, ,,	48,426	124,245	477	142	5′ 10″	2·5 to 1	·54
4	200 ,, 300 ,, 140 ,, ,,	67,085	145,800	364	162	6	2·1 to 1	·58
5	300 ,, 275 ,, 200 ,, ,,	110,991	191,100	318	196	6′ 6″	1·7 to 1	·67
6	400 ,, 275 ,, 265 ,, ,,	126,171	226,800	283	216	7	1·8 to 1	·72
7	600 ,, 220 ,, 400 ,, ,,	227,025	478,500	399	319	10	2·1 to 1	·98
8	800 ,, 220 ,, 530 ,, ,,	262,865	630,000	393	420	10	2·3 to 1	·95
9	1,000 ,, 215 ,, 700 ,, ,,	316,660	842,400	421	468	12	2·6 to 1	1·10

check upon the other. Where a motor is direct coupled to its load there is no need so far as the motor itself is concerned for a greater mass of foundation than that necessary to carry its weight. Thus, with a motor generator or rotary converter weight is of little moment, area and depth to attain good footing being the only items to call for consideration. Where a motor is geared direct to pumps or similar machinery it will of course not be treated separately. The foundation should be designed upon the basis of the whole self-contained unit of motor and machine, and the latter will probably be the predominant factor in influencing the dimensions. Under no circumstances should a direct coupled or geared motor be given a separate or independent foundation. It should be mounted on the same block as the machine it is to drive, so that should subsidence occur it will not affect relative alignment.

The examples given in Table XIII illustrate what may be termed conservative practice. The motor and dynamo weights per B.H.P. and KW. respectively are on the safe side, the depth in each case being greater than should be necessary under ordinary conditions. This is particularly the case in the second and fifth instances, in which the soil was probably of a very unstable nature. Generally speaking, for a belt-geared machine the weight of foundation per B.H.P. and the proportion of foundation and machine weights should be about the same as with the high speed vertical steam engine, and in this case the pressure on the soil will be substantially less as the dynamo-electric machine is lighter per unit of output. Instances 6 and 7 show that a self-contained machine such as a rotary converter requires only very light foundations of little depth if the soil be good. A weight of about half that of the machine will suffice, and this appears to be normal practice.

TABLE XIII

FOUNDATIONS FOR ELECTRIC GENERATORS AND MOTORS

No.	Machine.		Foundation.				Proportion of Foundation and Machine Weights.	Total pressure per Sq. Ft. on soil. Tons.
	Description.	Weight. Lbs.	Weight.		Base Area Sq. Ft.	Depth Ft.		
			Lbs.	Lbs. per B.H.P. or KW.				
1	75 KW. belt-driven generator, 850 r.p.m.	5,890	12,243	163	24	3·5	2·1 to 1	·34
2	100 ,, ,, ,, 625 ,,	10,000	36,000	360	40	6	3·6 to 1	·51
3	20 H.P. motor, belt drive, 775 r.p.m.	1,850	9,600	480	16	4	5·1 to 1	·32
4	25 ,, ,, ,, ,, 490 ,,	1,500	7,200	288	12	4	4·8 to 1	·31
5	45 ,, ,, ,, ,, 950 ,,	3,200	15,225	338	22	5	4·7 to 1	·37
6	500 KW. rotary converter, 500 r.p.m.	36,800	18,900	38	84	2	·51 to 1	·29
7	900 ,, ,, ,, 250 ,,	68,000	45,825	50	143	3·5	·67 to 1	·35

Pipe Trenches, Pits and Cable Ducts

There is hardly need to go very fully into the matters of trenches, cable ducts, etc., as the size, position and general design of these must be determined by the exigences of the particular case. Perhaps the most important point in connexion with pipe trenches is that they should be made amply large, not only to carry the pipes they are designed for, with plenty of room to get at the joints all round, but also to accommodate small extra pipes such as drains which at a later date are often run in the same trenches for convenience. Any one who has experienced the difficulties inseparable from making a large pipe joint in a small trench which scarcely gives clearing room for the flanges will agree that this is a most essential point. It is, however, one which designers frequently ignore, forgetting, for instance, that the nuts at the bottom side of a pipe flange should be readily get-at-able as well as the top. In the case of large exhaust pipes where the trenching has been scamped these bottom nuts are often much slacker than they should be, or may even be left off altogether. The author has known instances of this brought about solely by quite inadequate room. It is generally advisable that pipe trenches, wheel and dynamo pits should be drained, the bottom sloping gently towards the orifice. Failing such provision they are apt to accumulate water, oil and dirt, a highly undesirable state of affairs from all points of view.

CHAPTER IV

MATERIALS FOR FOUNDATIONS

MATERIALS. CONCRETE

SINCE concrete plays such an all-important part in foundation work it will be desirable to enter fairly thoroughly into its theory and preparation. It possesses the advantage over all other foundation materials of requiring a minimum of skilled labour once the forms are built. It is comparatively inexpensive, as homogeneous as solid stone, can be made into any desired shape at little extra cost, and requires no coping or special footing. It is also more lasting than any other form of construction and less liable to disintegration through shocks or vibration.

Concrete has been defined as an artificial combination of minerals which by means of chemical action become incorporated into a solid mass. For convenience its constitutents are termed respectively the "aggregate" and the "matrix"; the former expression applying to the combination of broken stone, gravel, etc., and the latter to the cement combined with water. This is the active agent without which adhesion between the particles of the former is impossible. Treating these two groups of constituents separately: there are various substances which may be employed to form the aggregate, notably ballast, broken stone and brick, earthenware, burnt clay, furnace slag, coke breeze, gravel and sand. These constituents are variously suited to different classes of

work, and as stability is the first essential of a foundation it is necessary to employ a heavy aggregate such as ballast, broken stone, gravel and sand. With regard to the two former, it is usual to specify that individual pieces shall not exceed a certain maximum size in any one direction, the maximum allowable depending to a great extent upon the class and size of the work. Normally, stones should not exceed 2 in. in any direction and should be well screened. Whatever may be the maximum size permissible it is highly desirable that the dimensions of the particles should not be too uniform. The smaller pieces fill up the spaces between the larger ones and thus make the mass more homogeneous than would be possible if the aggregate were of comparatively uniform size. In form it should be angular to assist adherence, and above everything it should be clean and entirely free from grease, dust, or dirt of any description. It should also be inspected for soft bad stone that may be crushed in the fingers, and if any appreciable quantity of this is present the whole should be rejected as it will not make good concrete. Soft red bricks are also unsuitable as they are liable to break under tamping and it is not certain that the matrix will find its way into such fractures. Clean sharp sand free from loam is preferable to any other, and where possible it should be obtained from sand pits rather than from the sea shore or from a river. The particles of these latter classes of sand will be to a great extent rounded by continual friction and will therefore not be so suitable.

The function of gravel in concrete is to assist in filling up the voids between the larger particles of ballast and broken stone. It is well known that the two mixed together occupy a smaller space than they do separately, roughly by about 20 per cent. to 30 per cent., and the reason is of course that the lesser gravel occupies to a certain extent the vacuities between the greater stones. From the point of view of

homogeneity the most desirable mixture for concrete is one in which the cement, water, sand and gravel exactly equal in bulk the interstices in the ballast or broken stone. What this latter may amount to is readily determined by immersing a sample of the ballast in water just level with the top of the mass and then draining off the water and measuring its volume. This experiment if carried out on a fairly large scale to ensure comparative accuracy is useful in contrasting different classes of ballast or stone, but it must be remembered that when cement, water and sand are mixed together their joint bulk is also less than when separate by about the same percentage, and in calculating proportions this shrinkage must be allowed for.

With a view to economy large " one man stones " thus termed since their weight is all that one man can conveniently carry—are often incorporated in the concrete. They increase its stability and save expense in several directions. Before use they should be thoroughly wetted, and they should not be placed nearer one another than six inches or closer to the surface than four inches.

Turning now to the matrix. The principal ingredient, namely Portland cement, must be the best of its kind for good results. Fresh cement of first class quality is grey in colour with a greenish tinge, and should it be at all brown it is either old or contains an undue proportion of clay. In conjunction with water and sand it forms a mortar in which the aggregate is bedded. The average chemical composition of good Portland cement is as follows :—

	Per cent.
Lime	60
Silica	20
Alumina and iron oxide	10
Magnesia, alkalies, sulphur, insoluble residue and moisture	10

Under the British Standard Specification for

Portland Cement it is provided that there shall be no excess of lime—that is to say, the proportion of lime shall not be greater than is necessary to saturate the silica and alumina present. Further, the percentage of insoluble residue shall not exceed 1·5 per cent.; that of magnesia shall not exceed 3 per cent.; and that of sulphuric anhydride shall not exceed 2·75 per cent. Of the physical properties of Portland cement that of fineness is of particular importance. The more finely ground the cement the stronger it is when combined with sand, and the higher the proportion of sand it will take without diminution of strength. Of late years the stringency of specifications has increased considerably in this direction, demanding, for instance, a residue not exceeding 3 per cent. on a 5776 mesh sieve and 18 per cent. on a 32,400 sieve. The widths of openings of these two sieves are respectively ·0087 in. and ·0037 in., and the figures of 5776 and 32,400 by which they are characterized are the number of meshes per square inch. The weight of Portland cement should range between 110 and 115 lb. per bushel, and its specific gravity should lie between 3·1 and 3·15. Its tensile strength when tested in the usual manner with neat cement briquettes should average not less than 400 lb. per square inch of section seven days after gauging, and 500 lb. per square inch after 28 days. With briquettes made up of three parts by weight of dry sand and one part Portland cement the tensile strength should average not less than 120 lb. per square inch after seven days and 225 lb. per square inch after 28 days. The authority to consult on these and kindred matters is the *British Specification for Portland Cement*, published by Crosby Lockwood and Son at 2*s*. 6*d*. net.

Sand is not an essential to the making of concrete, but if it is not used a much larger amount of cement will be necessary and the cost will be correspondingly higher.

The greater the proportion of sand the lower will be the tenacity of the resulting cement, and in practice it is never advisable to exceed proportions of one in four; that is, one part of Portland cement to four of sand. The opposite extreme may be taken as one in one and a half or two, but for foundation work it is usual to employ a proportion of one in three. To this will be added six or seven parts of aggregate, and the combination will be what is termed six to one or seven to one concrete as the case may be.

The quantity of water it is desirable to use in mixing is to some extent a debatable point. Certain authorities prefer plenty of water, while others recommend that it be used sparingly. So much depends, however, upon the porosity of the aggregate that it is not feasible to formulate any hard and fast rule and one must be guided by circumstances. Flooding must be avoided, but on the other hand sufficient water must be used to ensure the proper conveyance of the mortar into the aggregate, and the fluidity necessary for this is a matter of practical experience and common sense. Either fresh or salt water may be used, but if the foundation or any part of it is to be in sight it should be borne in mind that salt water gives rise to the formation of a white deposit which is both unsightly and difficult to remove.

The mixing of concrete may be performed either by hand or machinery, the latter course being cheaper where the quantity required is large. Hand mixing is of course the most usual, and it is generally carried out on a platform of boards.

The aggregate is first spread out and covered with the sand and Portland cement in thin layers. The resulting mass is mixed thoroughly in a dry state, turning over about three times being sufficient to effect this, and water is then added by degrees as mixture in the wet state proceeds. Turing over three times will suffice to bring about proper amalgamation, and the concrete is then ready for use. Owing to its

tendency to set it should be made in small portions at a time and used immediately. In large work where a considerable number of men are employed on mixing it is best to separate the process out into three heaps. The first gang will perform the dry mixing and will shovel on to the second heap where water is added. The men here will mix in the wet state and in turn pass to a third heap, from which after a final mixing the concrete will be thrown into the shoot. To secure accurate proportioning of the mixture it is usual to construct a wooden frame having a contents of one cubic yard, into which the materials are emptied before being spread on the mixing floor. Six to one concrete, made up of six parts of ballast, broken stone and gravel, two parts of sand, and one part of Portland cement will require for one cubic yard, 27 cubic feet of ballast, etc., 9 cubic feet of sand, $3\frac{1}{2}$ bushels of cement and say 25 gallons of water. Five men working hard can mix and throw downwards one cubic yard of concrete in five minutes.

The approximate cost of Portland cement concrete per cubic yard may be reckoned as follows :—

1 in 9 concrete	10/–
1 „ 7 „	12/–
1 „ 5 „	14/–

Bricks

The quality of brick to be used in foundation work is an important matter. For this purpose bricks should be of uniform texture, hard burned, and free from lime and other impurities. In size they should be uniform with smooth surfaces and straight angles, and no cracks or other defects should be allowed. Soft or common bricks of any kind should not be employed in any part of the foundation as they disintegrate rapidly under the varying strains set up by an engine. Suitable bricks are those known as Staffordshire, Ruabon, Cattybrook and Gault,

each of which have a high fracture and crushing strength. On the average, Staffordshire bricks measure 9 in. $\times$ $4\frac{1}{2}$ in. $\times$ 3 in.; Gault, 9 in. $\times$ $4\frac{1}{2}$ in. $\times$ $2\frac{3}{8}$ in.; Cattybrook, $9\frac{1}{2}$ in. $\times$ 4 in. $\times$ 3 in.; and Ruabon, 6 in. $\times$ $4\frac{1}{2}$ in. $\times$ $3\frac{1}{8}$ in. The approximate weights of these bricks—all of which are suitable for foundations—are 8·9 lb., 6·3 lb., 9·5 lb., and 9·1 lb. respectively. The weight of finished brickwork may be said to range between 125 lb. and 150 lb. per cubic foot, but it is as well to work out the actual weight of the class of brick to be employed as in certain cases there is a high percentage difference. If we assume a brick of $8\frac{1}{4}$ in. $\times$ 4 in. $\times$ 2 in.—another usual size—and a thickness of mortar of $\frac{1}{4}$in. the number of bricks per cubic foot will be 20·7 and the proportion of mortar to the entire mass 20·8 per cent.

As a material, stone scarcely merits separate consideration, and the reader is referred to Chapter VII for such information in this direction as may be necessary.

Cost of Foundations

In considering the question of cost it is essential to bear in mind the all-important effect of local conditions. It is possible for every item of the cost to vary considerably in different districts and under diverse circumstances, and for this reason no general estimate should be accepted without very careful checking in the light of the particular set of conditions prevailing. Piling or other preparation of the ground will add very greatly to the cost in a bad case, so much so that the item for foundations proper will be inconsiderable in comparison. Such cases cannot be dealt with in a general manner and it will therefore be necessary here to assume average conditions only, in which no piling or preparation is required and the soil is of a normal and good character. Under such circumstances and taking it for granted that materials are ready to hand and labour rates at the usual level,

it will not be very far wrong to take the cost of concrete foundation construction at 20*s*. per cubic yard. This sum will include excavation in a normal soil and carting, but excludes what may be termed extras, such as the cost of reinforcement of any part, flooring over basements, or glazed brick facings, etc. It is in short a figure which should cover the construction of a plain concrete block of normal shape. Necessarily it will not apply to very small foundations, which will cost more, and likewise it is inapplicable to a large installation of several foundations which may be constructed at a lower rate, particularly if concrete making machinery be employed. It is sometimes convenient to express the cost of foundations in percentage terms of the cost of the plant it carries, but such generalization is of course only possible or useful when dealing with definite classes of plant, as engines, dynamos and motors, the cost of which is fairly uniform in all makes. The percentage will be found to vary somewhat with the size of the plant, but in view of widely differing conditions it is impossible to say how or to what extent. In the case of a 1250 H.P. high speed vertical steam engine the cost of foundations amounted to 3 per cent. of the engine cost, while for a boiler feed pump costing £350 the expenditure on the foundation was £20, or 5·7 per cent. In other cases of high speed engines the percentage cost works out at from 1·5 to 2·5 per cent., and it would appear that in average practice it should range between the former figure and 3 per cent. Such figures are of course of little value as so much will depend upon the depth of foundation, its finish, and other similar points; they may however be of some use as affording a rough indication of percentage cost under average good conditions.

The relative cost of foundations for different types of engines is a matter of some interest. It was very ably dealt with by Mr. Edward H. Sniffin in a paper read before the American Street Railway Association,

and Fig. 12 is an adaptation to British conditions of a series of curves given in the paper. It should be mentioned that they apply to electric generating sets and cannot therefore be taken as a safe basis for comparison of engines only. Calculations were

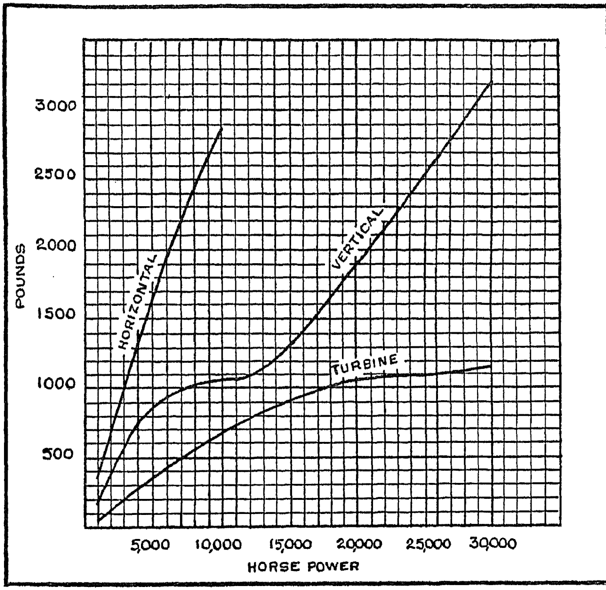


FIG. 12.—The Relative Cost of Foundations.

based upon the assumption that the plants were constructed as follows :—

1,000	H.P.	in	2–400	KW.	units.
3,000	,,	,,	3– 750	,,	,,
5,000	,,	,,	4–1,000	,,	,,
10,000	,,	,,	3–2,500	,,	,,
15,000	,,	,,	4–2,500	,,	,,
30,000	,,	,,	4–5,000	,,	,,

In the case of the horizontal engine the 10,000 H.P.

was assumed to be composed of 5–1,500 KW. units, and it was not carried beyond this total horse-power as horizontal generating sets are seldom of greater output than 1500 KW. The depth of foundation assumed was equal in every case and every size, namely, 15 ft., although this is manifestly unfair to the turbine, which requires only the lightest of beds. It was done, however, in order that all three types should be alike in having the condensing plant in a basement beneath them. Both the vertical and horizontal engines were assumed to be of the heavy, slow speed, Corliss type, and no calculations were made for the high speed enclosed engine so prevalent in Great Britain but unusual in America. The curve for this class of engine would lie between the "Vertical" and the "Turbine" curves, probably close to the latter as the foundation bulk assumed is admittedly excessive. These curves conform fairly closely to results obtained in practice.

CHAPTER V

HOLDING-DOWN BOLTS AND ANCHOR PLATES

Holding-Down Bolts, Ordinary Type

Holding-down bolts take many forms, and it will be useful to consider their comparative merits and suitability for different conditions. The simplest is the mild steel bolt of ordinary shape, having a head at one end and screwed at the other (*A*, Fig. 13). For average conditions with small or medium sized plant such bolts will suffice and are usual, but generally speaking they are not obtainable in large sizes of considerable length or over $\frac{3}{4}$ in. diameter, whence it may become necessary to employ bolts of the type shown at *B* (Fig. 13), consisting of a long rod screwed at both ends for nuts. Either type may be built into the foundation solid or secured by plates rendered accessible by pockets left in the concrete. The latter type, *B*, is used where it is desired to be able to withdraw the bolts, and in this case it is of course secured by a plate at the bottom and not built in. A variant of this type is the straight headless bolt (*C*, Fig. 13), seldom employed in the ordinary course but useful when machinery has to be fixed to an existing foundation where access cannot be had to the lower part of the concrete to cut a pocket for a plate. The holes in such a foundation must be drilled out to a suitable depth and the bolt grouted in solid. To secure better adhesion between the plain bolt and the surrounding cement grout it is

often customary to thread the bolt for a good part of its length or to raise projections on its surface with a chisel. These courses, however, are seldom necessary and it has been found that the former adds

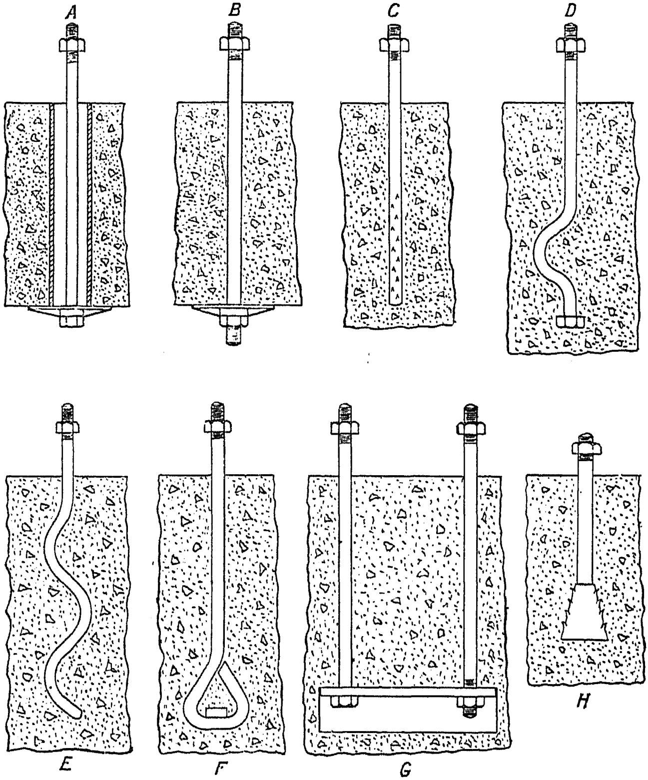


FIG. 13.—Types of Holding-down Bolts.

little or nothing to the resistance to withdrawal. The adhesion of concrete to a plain circular bolt is somewhere in the neighbourhood of 550–650 lb. per

square inch, although in reinforced concrete practice it is customary to allow a good factor of safety. Even assuming a much lower figure than the above it will be obvious that a plain bolt with no head and of average length makes quite a reliable job when grouted in solid. This question of bolt length is an important one and will be dealt with later. In the meantime we will revert to Fig. 13 and examine the characteristics of the other bolts illustrated.

Bent Bolts

Should it be impossible to give the requisite depth to a plain bolt the bent type shown at *D* may be used with advantage. The knee, which should be at the lower end to prevent pulling out of the upper surface of concrete, gives a good grip and entirely prevents turning of the bolt. Its angle should approximate to 90°, and the apex of the bend should be offset about three bolt diameters. A variant of this type is shown at *E*. It has the advantage of additional bends which increase its efficiency as an anchor, but the upper one is rather nearer the surface of the bed than is desirable.

Stirrup, Linked and Rag Bolts

The stirrup bolt shown at *F* is another good form which may either be built in solid or left free in a pipe. In the former case the stirrup at the foot will itself act as a most efficient anchor, but in the latter, two or more adjacent bolts are linked together by a round or flat iron bar passed through their stirrups, and in this case the anchoring is very secure. The same principle may be applied as shown at *G*, where ordinary bolts are connected together by flat iron straps. This system is useful where for one reason or the other very short bolts have to be used. It distributes the stress over a wide area and prevents all risk of the upper layer of concrete being torn off.

The well known "rag" or "Lewis" bolt, *H*, has its sphere in small work, and when grouted in with cement, lead or sulphur, preferably the former, is very effective, The hole in the foundation should be made to taper outwards, that is, it should be smaller at the top than at the bottom.

There are several forms of what are termed expansion bolts, but they are best avoided except under unusual circumstances. As their name implies, they depend for their action upon expansion of the lower part of the bolt after it has been placed in the concrete. Such bolts will generally stand well under a stationary load but are not reliable for use with running plant owing to the loosening effect of vibration. In any case they are only applicable to the smallest of machinery.

Length and Diameter of Bolts

In practice, the length of a foundation bolt is often determined by the depth of the concrete, the exception being where for one reason or another this is unusually great. Generally speaking this is very safe practice, but it is obviously a somewhat rough and ready rule which cannot always be relied upon. The accepted principle governing the length of foundation bolts is that this should be a minimum of thirty times the diameter, fifty times the diameter being considered safer and better practice. The figure applies to either cased or grouted bolts. In the former instance the depth to the plate is sufficient to prevent shearing of the surface concrete, and in the latter the area of adhesion is ample to give a sufficiently strong anchorage even in the case of rod bolts with no heads or plates. It should be borne in mind that the foregoing remarks apply only to heavy machinery such as steam and gas engines, electric motors driving by belt and plant of the type which obviously requires ample foundation and holding down

arrangements. Thus, the length rule does not apply to Lewis bolts and other small anchors which are only employed where holding down is a comparatively unimportant matter as in electrical boosting or balancing sets.

When determining the overall length necessary for a particular bolt the following measurements must be taken into account. Commencing at the upper end: A projection of about $\frac{1}{4}$in. above the nut, the thickness of the nut or nuts, the depth of the bedplate or lug, one inch more or less for grout, the buried length of the bolt, the thickness of the anchor plate, and the thickness of the bolt head or nut if a headless bolt be employed. In this latter case there should also be allowed not less than $\frac{3}{4}$ in. projection beyond the nut in order to have a little length in hand.

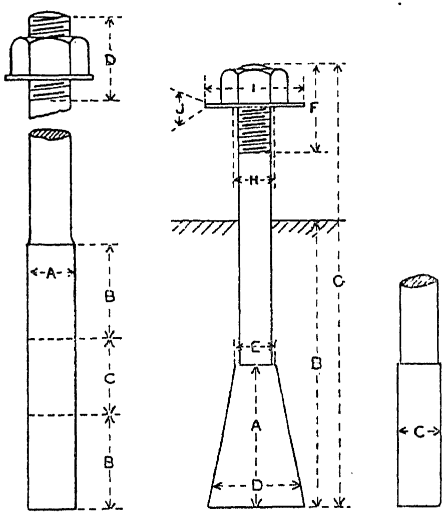
In practically every case the diameter of a foundation bolt is determined by the size of the holes in the bedplate. These follow certain conventions which experience has shown to be safe, and it is therefore only necessary to select a bolt of the largest size that will enter the hole, leaving a radial clearance of about $\frac{1}{16}$ in. When using bolts of large diameter the radial clearance may with advantage be increased to $\frac{1}{8}$ in. or $\frac{3}{16}$ in, but much will depend upon the accuracy of setting out and drilling of the bedplate. If the latter is not on the spot and there is any reason to doubt the accuracy of drilling it is best to use a smaller bolt in order to allow of greater play.

Standard dimensions of ordinary cotter bolts and Lewis bolts are given in the following tables and illustrations. Certain of the dimensions will be found to vary according to the maker but not to a serious extent.

TABLE XIV

Dimensions of Cotter Bolts (*A*, Fig. 14)

Dia. of Bolt.	A.	B.	C.	D.
in.	in.	in.	in.	in.
$\frac{1}{2}$	$\frac{3}{8}$	$1\frac{1}{8}$	$1\frac{1}{2}$	$1\frac{1}{2}$
$\frac{5}{8}$	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{5}{8}$	$1\frac{3}{4}$
$\frac{3}{4}$	$\frac{7}{8}$	$1\frac{1}{4}$	$1\frac{3}{4}$	2
$\frac{7}{8}$	1	$1\frac{3}{8}$	$1\frac{7}{8}$	$2\frac{1}{4}$
1	$1\frac{1}{8}$	$1\frac{3}{8}$	2	$2\frac{1}{2}$
$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$2\frac{1}{4}$	3
$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{1}{2}$	$2\frac{3}{4}$	$3\frac{1}{2}$
$1\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{5}{8}$	$3\frac{1}{4}$	4
2	$2\frac{1}{8}$	$1\frac{5}{8}$	$3\frac{3}{4}$	$4\frac{1}{2}$



A. B.

Fig. 14.—Dimensions of Cotter and Lewis Bolts. Tables XIV and XV.

TABLE XV

DIMENSIONS OF LEWIS BOLTS (*B*, Fig. 14)

Dia. of Bolt.	A.	B.	C.	D.	E.	F.	G.	H.	I.	J.
in.	in.	in.	in.	in.	in.	in.	in.	in.	in.	in.
$\frac{1}{2}$ . .	$2\frac{1}{4}$	5	$\frac{5}{8}$	$1\frac{1}{2}$	$\frac{5}{8}$	$1\frac{3}{8}$	According to requirements.	$\frac{9}{16}$	$1\frac{1}{2}$	$\frac{3}{32}$
$\frac{5}{8}$ . .	$2\frac{1}{2}$	6	$\frac{3}{4}$	$1\frac{3}{4}$	$\frac{3}{4}$	$1\frac{7}{8}$		$\frac{11}{16}$	$1\frac{3}{4}$	$\frac{1}{8}$
$\frac{3}{4}$ . .	3	7	$\frac{7}{8}$	$2\frac{1}{8}$	$\frac{3}{4}$	$2\frac{1}{4}$		$\frac{13}{16}$	2	$\frac{1}{8}$
$\frac{7}{8}$ . .	$3\frac{3}{8}$	8	1	$2\frac{1}{2}$	1	$2\frac{5}{8}$		$\frac{15}{16}$	$2\frac{1}{4}$	$\frac{1}{8}$
1 . .	$3\frac{3}{4}$	9	$1\frac{1}{8}$	3	$1\frac{1}{8}$	3		$1\frac{1}{16}$	$2\frac{5}{8}$	$\frac{3}{16}$
$1\frac{1}{4}$ . .	5	12	$1\frac{3}{8}$	4	$1\frac{3}{8}$	$3\frac{3}{4}$		$1\frac{5}{16}$	3	$\frac{1}{4}$
$1\frac{1}{2}$ . .	$5\frac{3}{4}$	$13\frac{1}{2}$	$1\frac{5}{8}$	$4\frac{1}{2}$	$1\frac{5}{8}$	$4\frac{1}{2}$		$1\frac{9}{16}$	$3\frac{1}{2}$	$\frac{1}{4}$

ANCHOR PLATES

A standard form of anchor plate or washer for use with the ordinary headed or cotter bolt is shown in Fig. 15 and the dimensions in various sizes are given in the adjoining table.

TABLE XVI

DIMENSIONS OF ANCHOR PLATES (Fig. 15)

Dia. of Bolt.	A.	B.	C.	D.	E.
in.	in.	in.	in.	in.	in.
$\frac{1}{2}$	5	$2\frac{1}{4}$	$\frac{7}{8}$	$\frac{3}{8}$	$1\frac{1}{2}$
$\frac{5}{8}$	5	$2\frac{1}{4}$	$\frac{7}{8}$	$\frac{3}{8}$	$1\frac{1}{2}$
$\frac{3}{4}$	6	$2\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{2}$	$1\frac{5}{8}$
$\frac{7}{8}$	6	$2\frac{1}{2}$	$1\frac{1}{8}$	$\frac{1}{2}$	$1\frac{5}{8}$
1	7	$2\frac{3}{4}$	$1\frac{1}{2}$	$\frac{5}{8}$	$1\frac{3}{4}$
$1\frac{1}{4}$	7	$2\frac{3}{4}$	$1\frac{1}{2}$	$\frac{5}{8}$	$1\frac{3}{4}$
$1\frac{1}{2}$	8	3	2	$\frac{3}{4}$	2
$1\frac{3}{4}$	8	3	2	$\frac{3}{4}$	2
2	9	$3\frac{1}{4}$	$2\frac{1}{4}$	$\frac{7}{8}$	$2\frac{1}{8}$

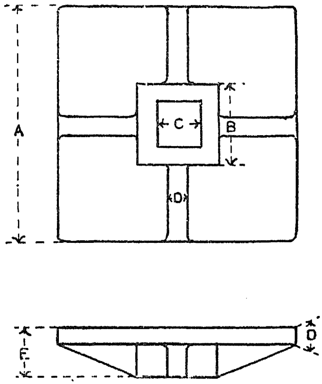


FIG. 15.—Dimensions of Anchor Plates. Table XVI.

It will be noticed that the hole is adapted for a bolt squared at the lower end in order to prevent turning when the nut is being screwed up. These plates are made of cast iron or mild steel, preferably the latter. The two essential points about an anchor plate are that it should have ample area to carry the load safely and should be so constructed and sufficiently thick to withstand the strains set up by uneven application of the load. This will be occasioned by roughness of its concrete seating, projections on which will naturally concentrate the pressure on a few spots. This is often unavoidable, and is of no consequence provided the plate is sufficiently thick and strong.

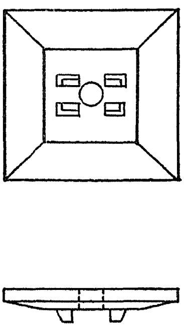


FIG. 16.—Anchor Plate with Lugs for Holding Bolt Head.

Another good design of anchor is shown in Fig. 16. Its particular feature is the provision of four lugs on the bottom side between which the head of a square headed bolt will fit. These lugs will of course prevent a cased and therefore ungripped circular bolt from turning when the bedplate nut is being screwed up, and the necessity for holding the head with a spanner inserted in the anchor pocket is thus obviated. When

circular bolts are grouted or built in solid this difficulty does not arise, as the grip of the cement or concrete prevents any tendency to turn.

A special and somewhat elaborate anchor used in the engine foundations of a New York power station is shown in Fig. 17. The bolts were encased by pipes, and a recess is provided in the surface of the plate in which the end of the pipe sits. The nut is held on the under side of the plate in a box which forms part of the casting, and is prevented from falling out by the pin shown on the left hand side. A certain amount of freedom is allowed in the box to permit the nut to adjust itself to the bolt in the event of the plate not being set quite correctly. In this particular anchor the principal dimensions for a 4 in. bolt are as follows :—Overall diameter 2 ft. 6 in. ; overall depth $8\frac{1}{2}$ in. ; diameter of pipe recess 7 in. ; thickness of ribs $1\frac{1}{2}$ in.

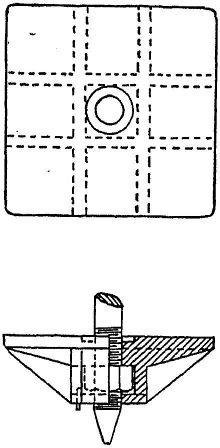


FIG. 17.—Special Type of Anchor Plate.

Care should be taken in employing odd types of plates not specially designed for the work. Thus, it is quite permissible to use the comparatively rough cast-iron washer employed by builders in the tying together of walls, but they should be carefully inspected for flaws and deformities, and to be on the safe side a rather larger diameter than that which may be deemed standard should be used. This latter precaution is also advisable with any type of plate where the bolt is placed in a casing instead of being grouted in solid. A typical cast-iron tie rod plate is shown in Fig. 18, and a table is given below of the dimensions generally adopted.

TABLE XVII

Dimensions of Tie Rod Anchor Plates (Fig. 18)

Dia. of Bolt.	A.	B.	C.	D.
in.	in.	in.	in.	in.
$\frac{1}{2}$	$2\frac{5}{8}$	$1\frac{3}{4}$	$\frac{9}{16}$	$\frac{5}{8}$
$\frac{5}{8}$	3	$1\frac{7}{8}$	$\frac{11}{16}$	$\frac{3}{4}$
$\frac{3}{4}$	$3\frac{1}{4}$	$2\frac{1}{8}$	$\frac{13}{16}$	$\frac{7}{8}$
$\frac{7}{8}$	$3\frac{3}{4}$	$2\frac{1}{2}$	$\frac{15}{16}$	$\frac{7}{8}$
1	4	$2\frac{3}{4}$	$1\frac{1}{16}$	$1\frac{1}{8}$
$1\frac{1}{8}$	$4\frac{3}{4}$	$2\frac{3}{4}$	$1\frac{3}{16}$	$1\frac{1}{8}$
$1\frac{1}{4}$	6	3	$1\frac{5}{16}$	$1\frac{3}{8}$
$1\frac{1}{2}$	$6\frac{1}{4}$	$3\frac{1}{4}$	$1\frac{5}{8}$	$1\frac{1}{2}$
$1\frac{3}{4}$	$7\frac{1}{4}$	$3\frac{3}{4}$	$1\frac{7}{8}$	$1\frac{3}{4}$
2	$8\frac{1}{4}$	$4\frac{1}{4}$	$2\frac{1}{8}$	2
$2\frac{1}{4}$	$9\frac{1}{4}$	$4\frac{3}{4}$	$2\frac{3}{8}$	$2\frac{1}{4}$
$2\frac{1}{2}$	$10\frac{1}{4}$	$5\frac{1}{4}$	$2\frac{5}{8}$	$2\frac{1}{2}$
$2\frac{3}{4}$	$11\frac{1}{4}$	$5\frac{3}{4}$	$2\frac{7}{8}$	$2\frac{3}{4}$
3	$12\frac{1}{4}$	$6\frac{1}{4}$	$3\frac{1}{8}$	3

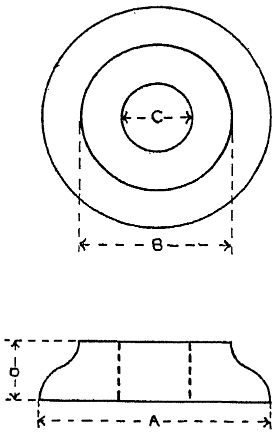


Fig. 18.—Dimensions of Tie Rod Anchor Plates. Table XVII.

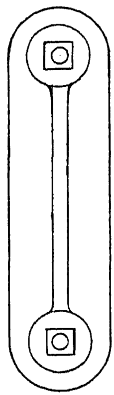


Fig. 19.—Double Anchor Plate.

A type of cast-iron anchor plate intended for

linking two bolts together is shown in Fig. 19, and the principal dimensions for long and short plates of this kind are given in Table XVIII.

TABLE XVIII

DIMENSIONS OF DOUBLE ANCHOR PLATES (Fig. 19)

Diameter of Bolt.	Size of Small Double Plate.	Size of Large Double Plate.
in.	in. × in.	in. × in.
$\frac{1}{2}$	8 × 4	16 × 4
$\frac{5}{8}$	10 × 5	20 × 5
$\frac{3}{4}$	12 × 6	24 × 6
$\frac{7}{8}$	14 × 7	28 × 7
1	16 × 8	32 × 8
$1\frac{1}{8}$	18 × 9	36 × 9
$1\frac{1}{4}$	20 × 10	40 × 10
$1\frac{1}{2}$	24 × 12	48 × 12

If a standard type of anchor plate cannot be obtained a very good substitute may be made from a piece of sheet steel with a hole drilled or punched in the centre. So far as overall diameter is concerned the figures given for standard plates may be adhered to, but if steel plate be used the thickness may be reduced to about half.

An entirely different method of anchoring a bolt is shown in Fig. 20. A special cast-iron box of the shape illustrated is built into the foundation, forming a pocket and at the same time an anchor. It is very convenient where it may be necessary to get at the bolts for the purposes of tightening up or withdrawal, but it is an expensive method and only worth while on very large plant.

In all the foregoing examples it will have been noticed that the anchor plates are secured to the bolts by means of nuts or else held in position by the head of the bolt.

This is generally considered the best practice, but the comparatively old-fashioned method of employing cotters is still largely adhered to although

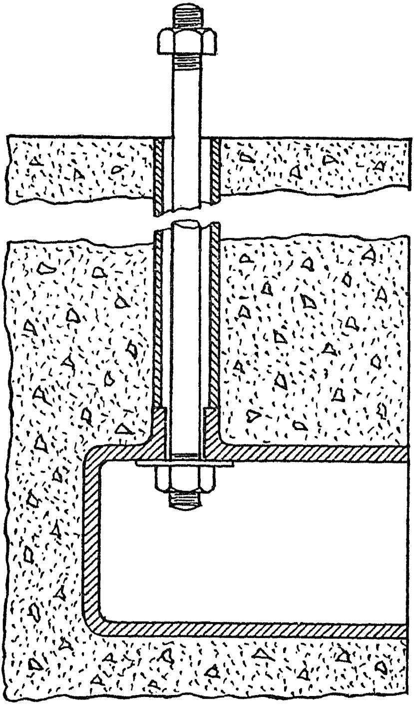


FIG. 20.—Cast-Iron combined Pocket and Anchor.

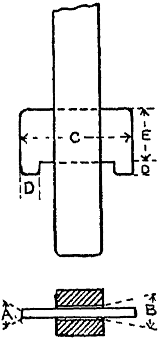


FIG. 21.—Dimensions of Bolt Cotters.

the slot in the bolt is a source of some weakness and the cost of manufacture is higher than that of a threaded bolt and nut. The usual arrangement is shown in Fig. 21, and approximately standard dimensions are appended thereto.

TABLE XIX

Dimensions of Bolt Cotters (Fig. 21

Dia. of Bolt.	A.	B.	C.	D.
in.	in.	in.	in.	in.
$\frac{1}{2}$ . . .	$\frac{3}{16}$	$\frac{1}{4}$	$1\frac{7}{8}$	$\frac{5}{16}$
$\frac{5}{8}$ . . .	$\frac{3}{16}$	$\frac{1}{4}$	2	$\frac{5}{16}$
$\frac{3}{4}$ . . .	$\frac{1}{4}$	$\frac{5}{16}$	$2\frac{1}{8}$	$\frac{5}{16}$
$\frac{7}{8}$ . . .	$\frac{1}{4}$	$\frac{5}{16}$	$2\frac{1}{4}$	$\frac{3}{8}$
1 . . .	$\frac{5}{16}$	$\frac{3}{8}$	$2\frac{3}{8}$	$\frac{3}{8}$
$1\frac{1}{4}$ . . .	$\frac{5}{16}$	$\frac{3}{8}$	$2\frac{5}{8}$	$\frac{3}{8}$
$1\frac{1}{2}$ . . .	$\frac{3}{8}$	$\frac{7}{16}$	$2\frac{7}{8}$	$\frac{1}{2}$
$1\frac{3}{4}$ . . .	$\frac{3}{8}$	$\frac{7}{16}$	3	$\frac{1}{2}$
2 . . .	$\frac{1}{2}$	$\frac{9}{16}$	$3\frac{1}{8}$	$\frac{1}{2}$

CHAPTER VI

EXCAVATION—CONSTRUCTION OF FOUNDATIONS

Excavation

The plan of the foundation having been set out from its centre line the first step in construction is excavation of the ground, unless the bed is to rest upon an already prepared concrete floor or raft, in which case the latter is simply roughened all over with the pick to promote adhesion between the two. Failing this arrangement the foundation will, according to circumstances, either be buried its full depth in the ground or, if there is a basement under the engine floor, only to the extent of a few feet. In the latter case the amount of excavation is not a serious matter as it is only necessary to go sufficiently deep to give the foundation a firm root in the ground. But the quantity of soil to be removed to accommodate a large foundation sunk to its full depth is considerable, and its excavation will have a material effect upon the cost of the work.

For estimating on this point the following data will be of service.

TABLE XX

Excavation

In excavating, each man should be allowed 5 ft. or 6 ft. breadth of face.

A man will throw a shovelful of earth from 6 ft. to 10 ft. horizontally and from 4 ft. to 5 ft. vertically upwards.

One man will move 10 cubic yards to a distance of 20 yards in a day.

A good excavator will dig and throw per hour :—

From ·75 to 1 cubic yard in loose ground.

·6 cubic yard in stiff clay or firm gravel.

From ·3 to ·5 cubic yard in hard ground where pick has to be used.

The total cost of excavating earth, including cartage, may be taken at approximately 3*s.* per cubic yard, and the cost of filling in at 1*s.* per cubic yard.

The cost of excavating increases at every 6 ft, in depth.

Fig. 22 illustrates the method of shoring up the sides of a trench while excavation is in progress. Poling boards about 8 in. wide, 3 ft. long and 1 in. to $1\frac{1}{2}$ in. thick are placed vertically against each side of the trench about every 3 ft. of its depth. On top of these, 9 in. by 3 in. waling planks are placed horizontally, and struts varying from 4 in. to 8 in. in diameter are wedged between them. The amount and style of timbering necessary will depend entirely upon the quality of the soil, but the method illustrated is the normal one.

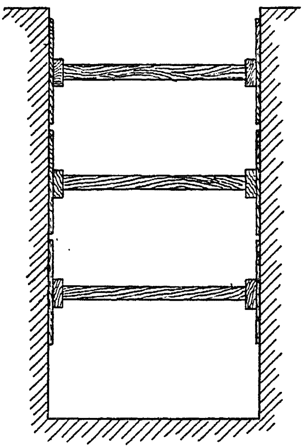


Fig. 22.—Method of Shoring Trench.

The infiltration of water during sinking operations may run up the cost considerably as it retards work and is sometimes very difficult to suppress. In the ordinary course it is possible to deal with such infiltration by keeping one part of the pit bottom lower than the rest and pumping the accumulated water therefrom.

The following tables give some useful information

on matters relating to excavation, and the figures are those which find general acceptance :—

TABLE XXI

Weight of Soils per Cubic Yard

	cwt.
Dry peat	7·5
Wet peat	15
Top soil	20
Dry sand	22
Common earth	24
Sandy loam	24
Marl	26
Clay	27
Common gravel	27
Wet sand	28
Gravelly clay	30
Rough water gravel	34
Grey chalk	36
Sandstone	37
Shale	39
Limestone	40

TABLE XXII

Natural Angle of Slope of Soils with the Horizontal

	deg.
Gravel	40
Dry sand	38
Sand	22
Vegetable earth	28
Compact earth	50
Shingle	39
Rubble	45
Clay, well drained	45
Clay, wet	16

TABLE XXIII

Maximum Depth of Vertical Face of Excavation which will Stand for a Short Time

	ft.
Clean dry sand and gravel	0 to 1
Moist sand and ordinary top soil	1 to 3
Loamy soil well drained	5 to 10
Clay, well drained	9 to 12
Compact gravelly soil	10 to 15

TABLE XXIV

SHRINKAGE OF SOILS AFTER REFILLING EXCAVATIONS

	Per cent.
Gravel	8
Gravel and sand	9
Clay	10
Loam and light sandy earths	12
Loose vegetable soil	15
Puddled clay	25

Rock increases 50 per cent. when broken and does not settle into less than original bulk.

FRAMEWORK FOR CONCRETE

Excavation being completed it is necessary to erect the skeleton of a framework to keep the concrete in position and give the finished block a smooth appearance. This is usually done in the following manner. Stout battens measuring about 7 in. by 3 in. of whatever height is necessary are fixed vertically at intervals of three or four feet around the outline of the foundation. They may be supported in the manner shown in Fig. 23, that is, by means of a strut at the upper end nailed on to the vertical post and a further strut at the bottom wedged in between the two. To the

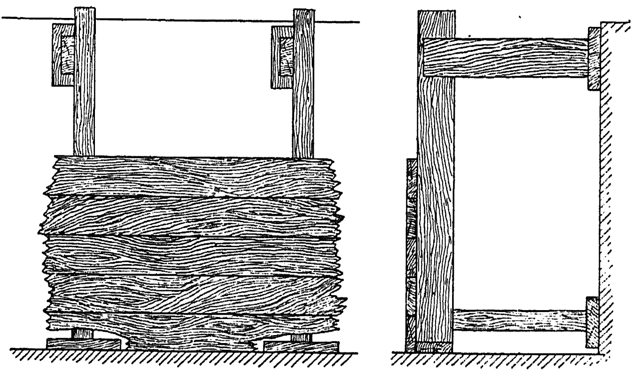


FIG. 23.—Method of Building Framework for Construction of Concrete Foundation.

inside of these uprights planks are nailed, forming the sides, the boards being added one by one as the mass of concrete rises. Two of the four sides must be built of boards sawn to the exact length so that the planks forming the other sides overlap them and thus make a neat job of the corners of the foundation. For the purpose of filling the frame with concrete the best arrangement is a rough wooden shoot long enough to reach to the bottom of the hole and capable of being moved to any part of the area. As the work progresses and the foundation rises, pieces may be sawn off the bottom of this trough which will thus always be kept at the most convenient length. Concrete should never be dropped any distance as this is apt to separate out the stones of different weight and thus render the mixing futile. Owing to the tendency of concrete to set quickly it should be made and used in small quantities at a time, being spread as equally as possible over the whole area in layers not exceeding 9 in. in thickness. It should then be tamped until water exudes from it over the surface. As each successive layer is shovelled on, the previous one should be roughened with the pick if at all set in order that the two layers may bind together properly. If this precaution is not taken the finished foundation will be stratified instead of homogeneous, and vibration troubles will almost surely arise. In a warm atmosphere an interval of ten hours is quite sufficient to allow the concrete to set to an extent that will preclude proper amalgamation.

A popular method of foundation construction, and one that has much to commend it, consists of building a permanent 8 in. brick wall in place of the usual wooden frame or former. Concrete is packed into the space thus enclosed, and in the case of large foundations at least the result is a cheaper construction and at the same time a more sightly one. All pockets are formed in the shell as the work progresses, and the ease with which this may be done has often caused

the system to be adopted for the first few feet of the block if not for the whole height. In the ordinary course a good hard brick will suffice for the purpose, but if much of the foundation is in sight, as is the case where condensing apparatus is situated under the engine, glazed facing bricks are preferable if their cost does not stand in the way.

POCKETS

It is usual in all but small foundations to provide pockets for the reception and adjustment of the holding-down bolt anchor plate (see Chap. V). This allows the bolts to be put in place after the foundation is completed and also permits of the ready replacement of a broken or injured bolt. Pockets consist of hand holes in the side of the foundation just large enough to take the plates and to allow of the nut being easily manipulated. They are formed as the foundation is built, and there are several ways in which this may be done. With brick or masonry foundations the proceeding will be obvious and it is only necessary to mention that it is usual to form the top of the pocket of a stone slab having a hole drilled at the centre for the bolt to pass through. For concrete foundations some sort of form is necessary, and this may either be built in a temporary

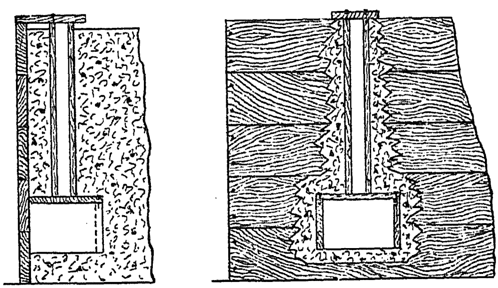


FIG. 24.—Wooden Former for Pocket.

manner of wood, or a permanent pocket built of brick or stone may be used. Fig. 24 illustrates the method of building a wooden frame together with the arrangement of the bolt casing. A box open at one end and having no bottom is constructed and placed in position when the foundation has been built up to the necessary height. The bolt casing is nailed to the loose top, its exact position being carefully determined, and the frame is then filled with sand to prevent collapse under tamping. The top carrying the bolt casing is then nailed on to the form and supported externally by a little concrete to prevent it shifting or the sides from bulging outward. Work on the foundation is now continued in the ordinary way, and when the concrete is set the temporary woodwork is prised out, leaving the pockets ready for reception of the anchor plates and bolts. It is of course possible to vary this method, as for instance by using a stone slab for the back of the pocket where it remains permanently in place. Such slabs may indeed be used throughout with advantage, and if strengthened internally with wooden struts it is not necessary to fill the pocket with sand prior to packing the concrete. The accurate placing of the bolt casing becomes a little difficult, as nails cannot be used. A good plan is to cut a plug of wood with a square upper half to fit in the casing and a circular lower half to fit in the bolt hole in the top slab. This will centre the casing and can readily be removed with the latter. If an iron pipe is used instead of casing it is easily centred at the bottom by drilling the hole in the slab just large enough to allow a tight fit, or if it be desired to keep the hole as small as possible and only just large enough for the bolt it may be countersunk in the top of the slab so that the pipe is given a footing. Centring at the top end of the casing or pipe is guided by a templet of the bed plate or by accurate measurements. The fixing of the casing at this end must be secure as there is

always a chance of it becoming shifted when packing the concrete. It is often sufficient to nail the top of the casing to the side frame boards as shown in Fig. 24, but many stronger methods will suggest themselves.

The building of brick pockets in a concrete foundation after the manner shown in Fig. 25 will obviate all necessity for frames. The top of the pocket may consist of a piece of iron plate drilled centrally for the bolt and built in, or alternatively, a stout piece of wood cut to fit the brick pocket closely may be supported in such a manner that it can be withdrawn after the concrete packed on top of it has set. Should

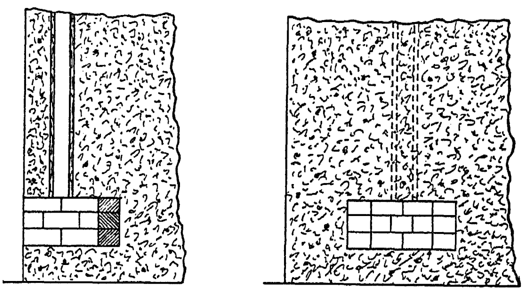


FIG. 25.—Construction of Brick Pocket.

the foundation or other long bolts be handy the wooden tops may be suspended from them, the bolts being in turn suspended from the templet or strong attachments to the foundation frame. A rather unusual pocket of cast iron which in addition to forming a hand hole acts as an anchor plate is described in Chap. V.

TEMPLETS AND BOLT CENTRING

Templets for the correct location of bolt centres may be made from 1 in. by 4 in. timber, the breadth

of which is sufficient to allow of holes being bored for bolts up to about 2 in. diameter. Strong bracing with diagonal battens is essential to accuracy. Measurements for the construction of the templet are taken either from the bed plate or drawings, and if possible all the bolt holes should be laid out on one templet to avoid mistakes. When parts of the foundation are of different heights the templet should be stepped, and more than one should not be used unless the size of the machinery makes it absolutely necessary. It is sometimes a difficult matter to fix the templet rigidly at its proper height, but usually this may be done by supporting it on the timber form of the foundation. In the case of brickwork where such forms are not used special scaffolding must be erected. The templet being placed in position at the right height the bolts are suspended in the holes with a full nut and are centred at the bottom in a suitable manner. If they are to be built in solid this is not necessary provided care is taken in packing the concrete round them. Should it be proposed to insert the bolts after the foundation is finished the pipes or casings are fixed to the templet, the upper ends being arranged to finish about level with the top of the foundation. When pipes or casings are fixed in this manner it is important that the ends should be plugged in order to keep dirt out.

Perhaps the most usual practice, at any rate in the larger classes of work, is to build the pipes or casings in with the bolts in position, and here it is necessary that the former should lie concentrically with the latter. To effect this, special care must be given to centring the bolts top and bottom, and for this purpose very simple expedients will suffice. For instance, a large nut or a hollow wooden cylinder or cube will keep the bottom end central in the pipe or casing if dropped down the bolt, and the top end in the case of a pipe may be readily centred by means of a few long nails driven either upwards or down-

wards through the templet, round the bolt holes, in such a manner that they make contact with the inside of the pipe and thus keep it central with the bolt.

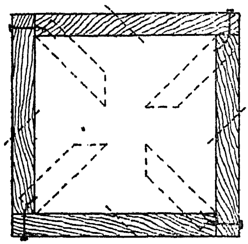


FIG. 26.—Method of Constructing Wooden Bolt Casing.

Wooden bolt casings as usually constructed are often somewhat difficult to remove, having to be broken up and taken out in small pieces. A method of getting over this difficulty is shown in Fig. 26. The wood used should be as straight grained as possible, and the sides which are of equal width should be lightly nailed in the manner shown and not in the way that a box is usually made. When it is required to remove such a casing it is only necessary to split the sides from top to bottom at an angle of 45 deg. with a chisel and then prise inward off the nails. It is also a good plan to taper the casings as this will much facilitate their removal.

If pipes are preferred to wooden casings the best kind to employ for average sized work is ordinary wrought-iron pipe. For very large bolts special pipes made of sheet iron are sometimes used, and earthenware pipes are also of service, but on the whole the ordinary wrought-iron pipe is preferable.

The finish of a concrete foundation is not often a matter of any importance, but to this end a good part of the surface is sometimes trowelled over in order to cover the natural roughness of the concrete. A cheaper way of securing a smooth finish is to deposit a 2 in. layer of cement mortar against the frame as the work progresses. This is churned up with a special form of long bladed spade, and the result is a smooth surface which for most purposes will be quite satisfactory. If rounded instead of square corners are desired the best course is to nail semicircular

fillets of strong tinned iron in the corners of the frame.

Before proceeding with erection of the plant, it is very necessary to give a concrete foundation ample time to set. The period will vary with the size of the block, but a foundation for a large engine should be given from 6 to 8 weeks to set.

CHAPTER VII

CONSTRUCTION OF FOUNDATIONS

Brickwork Foundations

Solid brickwork foundations are popular for small machinery and engines, as for such work they are frequently cheaper than concrete and more readily constructed. It may not always be easy to obtain the right class of ballast, and the cost of mixing concrete in small quantities is disproportionate. Bricks are generally handy, and their use does not involve the amount of plant and preparation inseparable from concrete. They are now seldom used for large foundations as conditions are quite different. A disadvantage lies in the fact that oil has a very deleterious effect upon brickwork and mortar, rotting it in course of time, and for this reason special precautions must be taken to prevent accumulation of oil or grease on any part of a brickwork foundation. Short of the provision of a stone coping a layer of cement on the top or any part which oil is likely to touch is the only sure remedy.

There is little in the actual building of a brick foundation to call for remark. The work is subservient to ordinary building practice, and the chief point to note is the necessity for first class materials and workmanship. Cement mortar made of one part of cement to two parts of clean sharp sand should be used exclusively, lime mortar as ordinarily employed for building walls, etc., being quite unsuitable. The thickness of the mortar joints should be about $\frac{1}{4}$ in.

It is best to construct the foundation solidly throughout of bricks laid in courses, but when the machinery is light and small and its base covers a good area considerable economy may be effected by using bricks in courses for the outside only, filling in the centre which does not directly support the bedplate with broken bricks or rubble cemented together with mortar. A footing similar to that of a wall or pier should be given to the foundation in the interests of stability, and from this the sides will rise vertically in the ordinary way. Simple construction of this nature will suffice for the average small engine foundation, but in dealing with the larger sizes it is better to allow a reasonable batter which will materially improve the structure in every way. It is also desirable to lay well tarred and sanded hoop iron 1 in. to $2\frac{1}{2}$ in. wide and $\frac{1}{16}$ in. to $\frac{3}{16}$ in. thick in double rows along the course every 3 ft. or 4 ft. in height, as this will add to the strength. If the edges of the strips are jagged they will have a much better hold on the brickwork.

With brick foundations which appear above the floor line a stone coping is often considered desirable from the point of view of appearance, but a much cheaper alternative is to use rounded glazed bricks at the edges, a practice which is sometimes applied to concrete foundations, A stone coping, however, is frequently required to distribute the weight of the engine, which may be concentrated at a few points, and it is almost a necessity in order to keep oil and water from the brickwork. If other trustworthy means can be designed for this latter purpose it may only be necessary to provide slabs of stone directly under the actual bearing points of the engine or machine. If the bedplate is continuous and more or less covers the whole area the weight will be sufficiently distributed to allow of a coping being dispensed with,

Stone Foundations

The use of stone in foundation construction is rare as it possesses no particular advantages and in all but exceptional cases is more expensive than concrete and at the same time less satisfactory. There are, however, occasions when stone in one form or another may be used to advantage, more particularly for small engine beds, and for this reason it will be well to give it some consideration.

There are three methods of constructing stone foundations and choice must be guided by local conditions such as the quality of the stone available. The simplest and cheapest consists of a rough masonry formed of rubble of large size set in cement mortar. Within its limitations as regards the size of engine or machine that may be thus bedded this is fairly satisfactory construction and works out at about the same cost as brickwork. It is, however, rough and unsightly and generally requires a dressed stone coping to distribute the weight over a sufficient area, which will add materially to the cost. The weight of this style of construction is about the same as that of concrete, namely, 150 lb. per cubic foot.

According to its character rubble may be either built up roughly or uncoursed in the manner indicated, or it may be coursed irregularly, worked up to course, or coursed. The difference is made clear in Fig. 27 and the method to be adopted should depend

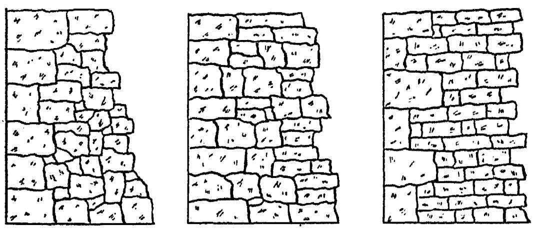


Fig. 27.—Rubble, Built up to Course and Coursed Masonry,

upon the nature of the stone, which may render it particularly suitable for one or the other class of work. Thus, some stones readily break up into approximately regular shape, whilst others, owing to absence of distinct lines of bedding, will only work into irregular lumps. The best stones, such as granite and sandstone, scabble or break up into approximately true shape freely, but crystalline stones or basalts are difficult to handle in this respect and tend to fly under the hammer. Whichever construction be employed it is important that bond stones should be inserted about every superficial yard in order to tie the mass properly together. These should run from the face into the body of the foundation as far as may be practicable, and they should be inserted from opposite sides alternately.

In the second method the main body of the foundation consists of rubble cemented together as before, but this is faced with Ashlar stone of whatever thickness may be deemed best. The appearance is very pleasing but the cost is higher, even when the proportion of the Ashlar facing to the rubble is low. Unless properly bonded as mentioned above there is a probability of unequal settlement of the two parts. Pockets, if required, can be made by the aid of forms round which the rubble is carefully laid and cemented, but it is better in this class of work to build the pockets up entirely of stone, slabs being cut specially to shape.

The third method is by far the most expensive since it involves the use of cut and dressed stone such as limestone, sandstone or granite. To this class of masonry the term Ashlar is applied, and up to thirty or forty years ago Ashlar stone was used almost exclusively for foundations. In such work the courses are uniform in depth or nearly so, the depth of the stones being from 12 in. to 14 in. on the face. The term Ashlar is qualified by such additions as rock, wrought and quarry-pitched according to the face

put on the stone, but usually the blocks are used in the condition they come from the saw if properly square, as a surface of this nature enables the mortar to adhere well. For this reason it is undesirable that the surfaces should be very smooth, but they must be true to allow of close fitting, and if at all winding are therefore dressed with the chisel. Before bedding in the mortar each stone is fitted into place in such a manner that the joints will not exceed $\frac{1}{8}$ in. When laid, the vertical joints are filled with cement grout which is stirred up between the stones with a piece of hoop iron to make sure of complete filling. It is kept in by means of cement plastered on the outside of the stones over the joints.

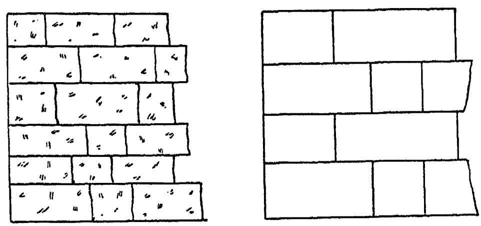


FIG. 28.—Block in Course and Ashlar Masonry.

The class of masonry known as Block in course (Fig. 28) is somewhat similar to Ashlar, differing only in the roughness of the stone and the depth of the courses. This latter may range from 3 in. to 12 in. according to the size of the stone employed, and the length of the stones will be from four to five times their depth. The courses are not necessarily uniform in depth as is the case with Ashlar masonry. Both these classes of construction are comparatively expensive for foundations, and the former more so than the latter. With both a good deal of work is entailed in forming pockets, the stones of which must fit

accurately like all the rest. Further, the bolt holes have to be drilled, and since the stones employed are large and heavy the cost of handling them is considerable.

Grouting

Grouting, whether of the bedplate or foundation bolts, is an operation that should be very carefully carried out, particularly in the former case. A good deal depends upon correct preparation of the grout, but it is even more important that it should be properly applied, and so far as the bedplate is concerned this is not always an easy matter. With prime movers certainly and also with many large driven machines it is not feasible to place the bedplate direct on the top of the foundation. It should be levelled up by means of machined iron wedges of ample area and thickness placed in pairs one on top of the other in such a manner that when the upper one is driven it raises the bedplate. The space between the latter and the foundation is then filled with grout, and upon this and the wedges the engine rests in a proper condition of level. If in course of time the bedplate begins to work loose it is generally safe to anticipate that it will rapidly grow worse in this respect. The slightest movement must inevitably result sooner or later in grinding down the grout and loosening the wedges, particularly if oil be present, and it is then futile to tighten up the holding-down bolts as is usually done. This only throws upon the bedplate a strain it is not suited to bear and may easily end in fracture. The proper course is to relevel and regrout it, and besides being the most satisfactory one it is the cheaper in the long run. Where this trouble is appreciated it has frequently been anticipated by providing iron plate seatings for the bedplate. Their edges should be raised so as to prevent oil and water finding its way into the foundation, as this is often the root of the whole trouble. Another good plan

to prevent lateral movement is to arrange for lugs to be cast on the underneath side of the bedplate and to provide holes in the foundation into which they will fit. This will help materially in preventing end motion, to which engines—particularly of the horizontal type—are always liable.

For all practical purposes there are five kinds of grouts, of which the most widely used is that made of equal proportions of Portland cement and sand well mixed with water. Rust, sulphur, lead and plaster of Paris grouts have their uses, particularly in small work, but for the average purpose they are not to be compared to the cement grout. The bedplate of the engine being levelled up by means of wedges as described the first step in the process of grouting is the provision of a dam round the bedplate to keep the grout in place until it sets. This may be made of clay, sand or wooden battens set back two or three inches from the bedplate. After thoroughly wetting the surface of the foundation the grout of a thick creamy consistency is poured, and the result will greatly depend upon the care with which this is done. The conditions are eminently favourable to the formation of air and water pockets, and the only way to avoid these is to keep the mixture well stirred with a piece of hoop iron or some other suitable implement as it runs into place. The sluggish flow of grout gives plenty of time for the heavier particles to sink and separate out, with the result that sections of the joint remote from the point of pouring may be filled with a grout chiefly composed of water. It is also possible for air to become trapped, the consequence of which will be the formation of voids between the grout and the bedplate, a very undesirable thing. After about twelve hours a poured grout will be firm enough to allow of the removal of the dam in order that the surface may be faced up. In certain instances it will be found possible to tamp the cement into the joint, and in such cases while the proportions of cement and

sand will remain the same, a smaller proportion of water must be used in mixing. To tamp well the cement should be of a firm consistency and it should be rammed in as hard as possible. It will set in about fifteen hours, before which time it should be finally faced up to look neat.

In the case of large bedplates it is very usual to fill, or partly fill, them with concrete in order to improve the grip on the foundation and to deaden noise. Concrete of the usual proportions is employed, but since with certain Portland cement concrete has a tendency to expand and possibly crack the bedplate some engineers prefer a filling of sand which so far as noise is concerned is quite as effective.

The grouting of holding-down bolts is a simpler matter as there is no tendency to the formation of air or water pockets. The cement being poured vertically, surplus water will rise to the top and flow away from the casing while the body of the material will sink to the bottom. It is therefore only necessary to keep the grout well stirred while pouring is going on.

A rust joint or grout is made from iron chips or borings which have been immersed in a solution of sal-ammoniac, or, if preferred, sal-ammoniac and salt. A strong dam or wall of some sort must be provided against which the joint can be rammed, and this must be done very thoroughly and a little at a time until the joint gives off a sound like that of solid metal. The main advantages of a sulphur grout are that it will readily flow into very small spaces and shrink little if at all when cold. On the other hand, it cannot be trusted to adhere as well as cement or rust and is apt to break up under vibration. It is of course out of the question as a grout for any but very small and special work, but in such spheres it has its uses. In melting sulphur it is necessary to be careful not to overheat, in which case it becomes thick at the bottom of the pot. When properly heated it pours

like water and is thus a very easy grout to handle. A further material suitable for the grouting of small bedplates and bolts, such as those of electric motors, is plaster of Paris. The rapidity with which it sets makes it particularly useful on emergency jobs, but it also necessitates special care and the plaster should be mixed and used only in small quantities at a time. The best proportion is two of plaster and one of water by weight, and such a mixture is stated to be able to sustain a load of 500 lb. per square inch one hour after setting and 2,300 lb. per square inch after twenty-four hours.

Whatever material may be used for the grout it is very necessary that it should be protected from oil, which in time will rot any joint. The chief risk of this lies in accumulations of oil inside the bedplate, and the most effective method is obviously so to arrange matters that it cannot get in. Failing this, a coat of shellac, or preferably paint, will be effective if renewed from time to time.

In this connexion an interesting example of foundation failure was given in a recent issue of *Power*. The foundation in question was built of good Ashlar blocks, but they had become saturated with oil during many years of service and the cement had softened and squeezed out of the joints. Settlement took place, especially under the crankshaft bearings, and finally the bedplate broke. It was decided to scrap the old engine and replace by a 1,700 H.P. horizontal tandem-compound engine, and it was recognized that the foundation should also be rebuilt and strengthened. This, however, was not done owing to lack of time, and the new engine was erected on the worn out foundation with the following results. Upon starting up movement was noticed, and although the joints in the stonework were wedged open, cleaned out and rejointed, and the foundation bolts pulled up tight, neither the engine nor foundation could be made firm. The oil was then cleaned out

from the bottom of the foundation and the joints, the latter being again filled with cement, and an improvement was noticed. But the mistake was made of not lifting the flywheel and shaft in order to take their weight off the bearings, and the holding-down bolts were also not slacked out or the bedplate levelled. The consequence was that the latter had no chance of adapting itself to the new conditions and very shortly cracked near one of the bolts.

Ferro-Concrete Construction

In large foundations, particularly those of steam turbines and horizontal engines, it is frequently necessary to construct tunnels for the purpose of carrying pipes, etc., or basements for the housing of condensing plant. For such situations it is desirable to employ a ferro-concrete construction to give strength to what may possibly be a weak part. In the ordinary course it should only be necessary to reinforce arches and perhaps the sides of pits or trenches such, for instance, as the pits provided to accommodate the lower halves of electric generators, but other cases may arise in which this useful method can be employed to advantage.

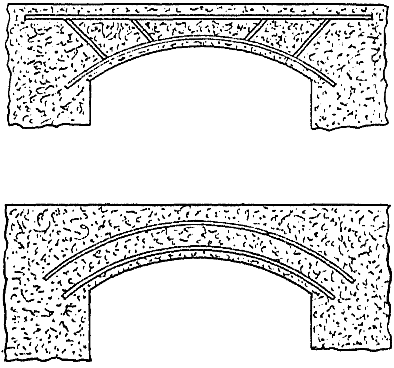


Fig. 29.—Methods of Reinforcing Concrete Arches.

Fig 29 illustrates two methods of arch reinforcement. In the first of these, which is the Monier form of construction, ligatures are used to connect the top and bottom armatures, but the second is less elaborate and may be made even simpler by omitting the top armature where reinforcement is only a precaution and the concrete alone is capable of carrying the tensile stress.

The strengthening of pit or trench walls is best carried out by two or three strips of expanded steel enclosing the sides and ends and overlapping where they meet. They should be spaced about 8 in. apart and the concrete carefully tamped between them.

The flooring over foundation basements is sometimes called upon to carry considerable weight as, for instance, when the engine is dismantled. For this reason it must be strong, and it must certainly be fireproof. An ordinary form of brick, concrete and tile construction is shown in Fig. 30. This is suitable

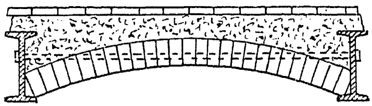


FIG. 30.—Brick, Concrete and Tile Flooring.

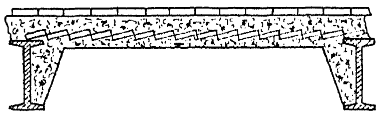


FIG. 31.—Reinforced Concrete and Tile Flooring.

for a span of from 4 ft. to 6 ft., or greater provided there is room for sufficient rise, which should not be less than one-tenth of the span, and an ample thickness of concrete for stiffening purposes. A tiled floor of this kind in which bricks 4½ in. deep are

used will weigh about 50 lb. per square foot of surface plus the weight of the concrete at, say, 150 lb. per cubic foot. In Fig. 31 is shown a much lighter but at the same time a strong type of floor reinforced with expanded metal. One or more sheets may be used as occasion warrants, or where it is deemed advisable a stronger combination built up in the usual manner of rods may be employed with advantage. Such flooring is not only strong and fireproof but is also cheap and very suitable for the purpose of covering in engine basements.

CHAPTER VIII

VIBRATION—ITS CAUSES AND EFFECTS

VIBRATION

OF all the problems surrounding the design and erection of machinery that of the prevention and suppression of vibration and noise is one of the most interesting and at times most intricate. All running machinery, even the most perfect, tends to set up vibration to a greater or lesser extent, and disturbances of this nature are often extremely elusive, difficult to trace and more difficult to remedy. The subject is of paramount importance to engineers in view of the pains and penalties to which owners of plant faulty in this respect are or may be liable. Should an action brought against the possessor of such a plant be successful, as it often is, he will be bound to take whatever steps may be necessary to mitigate the nuisance, even if this should call for the entire remodelling of the plant or its abolition. Hence the matter is a serious one and should be very fully considered in the first instance. The circumstances of the case may not render it a difficult or costly one to deal with when the foundation is under construction, but after the plant is fixed the alterations necessary to check the trouble may be both expensive and inconvenient, particularly if the machinery is of any size.

In a paper read before the Société des Ingénieurs Civils de France in 1905 M. Prache divides the noises and vibrations arising from running machinery into

two classes ; firstly, direct noises transmitted by the air directly, and secondly, indirect noises and vibrations conducted by the ground and walls, often to great distances. As instances of the former he gives the explosions of firearms and the aerial vibrations set up by the pistons of large gas engines, both of which give rise to intensely sonorous waves capable of making heavy objects vibrate at a distance even through partitions and walls. This is a frequent trouble with large gas engines, and when the period of vibration of the engine synchronizes with that of the building the disturbance is at its worst. Closing in the front of the engine or the provision of tightly fitting windows and doors are the only remedies to prevent the spread of such aerial vibrations. It is, however, with what are termed indirect noises and vibrations that the engineer is chiefly concerned, and since the propagation and transmission of these depends upon such a large number of variables the problem is frequently a very difficult one. M. Prache emphasizes the generally accepted dictum that to prevent the transmission of vibration from a machine it is necessary to interpose between it and the soil a substance capable of absorbing such vibration by continual variation in its thickness. Such a substance to be effective must be so perfectly elastic that it can be compressed several times a second for a period of years without ceasing to return in each instance to its original dimensions. In view of its situation it is also eminently important that it should be more or less waterproof according to conditions, immune from the attacks of insects and vermin, incapable of taking a permanent set, and of such a consistency or structure that it will not become pulped or squeezed out. It will of course be understood that as a general rule the mass of concrete in a foundation is sufficient to absorb the vibrations set up by an engine, and it is not suggested that insulation from the soil is necessary in every case. It is useful and indeed essential

where the soil is of a nature particularly suited to the transmission of vibration or where the engine or machine is so badly balanced that it creates more than usually bad disturbances. It is equally as important where for one reason or another a foundation of sufficient bulk cannot be provided as, for instance, in the case of factory machinery installed on hollow floors. Here the vibration set up is often very intense and it can only be overcome by employing a good type of insulator between the machine and the floor.

Engine Vibration

The subject of engine vibration is an extremely complicated one and a study in itself. So many causes may contribute to its production that it is often a matter of the closest inspection and most careful experiment to locate with any certainty the reason or reasons of vibration. They may be inherent in the design of the engine, or it is possible that some extraneous matter such as a sprung shaft or inefficient holding-down arrangements may be the cause. The type of engine has naturally a considerable bearing upon the question of vibration. Thus, a vertical engine sets up vertical oscillations in the foundation and also a tilting oscillation, which latter effect arises out of the fact that the centre of gravity of the mass is not in the line of motion of the reciprocating parts. A horizontal engine on the other hand oscillates its foundation in a horizontal direction parallel to the line of motion of the piston, and as explained in Chapter II it also sets up a tilting oscillation. Broadly speaking, these are the effects produced in the foundations of the principal classes of engines. They arise from numerous causes and combinations of causes such as an unbalanced state of the reciprocating parts, the couple set up in two line engines tending to produce endwise tilting, the

variable velocity of the reciprocating parts due to the finite length of the connecting rod, and possibly lack of balance in some purely rotary part. Several excellent treatises have been written upon the subject of engine vibration, and to these the reader is referred for a full discussion of the various causes and their treatment so far as the engine itself is concerned. We are dealing here solely with the suppression of vibration by means of suitable foundations and are therefore not directly concerned with questions of engine design.

In contrasting vertical and horizontal engines it is obvious that disturbances set up by the latter should be easier to isolate than those of the former. The oscillations of the foundation in the case of a horizontal engine being principally in a horizontal direction it is only necessary to keep the foundation clear of the surrounding soil on all four sides to eliminate any direct effect. Even if this is not done in the first instance the minute but continual ramming of the foundation block against the soil tends to the formation of a small but effective space around it. In such a case horizontal oscillations can only be transmitted through the base of the foundation, which if more or less rigidly bound to the soil will thus set up vibration in it. To obviate this and to damp the lesser vertical oscillations it is necessary to keep the base of the block as free as possible from the soil by the introduction of a thick layer of well rammed sand or one or other of the special insulators now manufactured for the purpose. To some extent the vibration of the block will keep it free at the bottom if the soil is dry, but while such freedom may be sufficient to damp the horizontal and angular oscillations it will of course have no effect whatever on those which act in a vertical direction. The vertical engine is a more difficult problem because most of the disturbance it sets up takes place vertically. Freedom at the sides is still important for

obvious reasons, but the base of the block through which the vertical forces pass to the soil is the portion demanding particular care and isolation. We know from experience that as a rule engine vibration is absorbed more or less satisfactorily by the foundation and the soil in its immediate vicinity; but a vein of rock or a very wet soil will transmit vibration to a surprising extent, and it is in such situations that the greatest trouble is usually experienced. An important point to bear in mind when considering this question is the joint and possibly cumulative effect of a number of engines running in close proximity to one another or bedded on a common foundation. Electric power stations are particularly subject to this trouble, the conditions being eminently favourable to the production of what may be termed compound vibratory effects. When two or more engines are running side by side occasional synchronism of their vibrations is inevitable, especially if their speeds are the same or nearly so. If the speeds are unequal periods of maximum vibration will be followed by periods of rest in more or less regular sequence. The higher the speed of the engines the more frequently will their vibrations come into phase, but this does not imply that high speed engines are more likely to create nuisance than low speed. On the contrary, it is generally admitted that the reverse is the case, as the comparatively greater amplitude of low speed engine vibrations are more marked and productive of annoyance than the lesser though more frequent high speed vibrations. In the case of similar engines of the same speed driving alternating current generators in parallel the resulting combined vibrations will be constant and there will be no alternate periods of quiet and disturbance, but their intensity will be more or less a matter of chance depending upon the angular relationship of the cranks of the various engines at the moments of paralleling. This, however, will obviously not be the

case where the engines are of different speeds, for although running synchronously the efforts which produce vibration will be taking place at different times and will therefore tend to set up alternate maximum and minimum periods of disturbance.

The transmission of vibration through the soil is a matter beset by much complexity. An oscillating foundation propagates vibration waves which spreading out from the centre gradually become diminished in amplitude and finally die out. There is, however, always the possibility that the nature of the soil may be variable and such that the disturbance travels more in one direction than another, and from this cause arises the frequently known phenomenon of vibration being particularly discernible at one spot or in one direction. Further, it is necessary to recognize the possibility of reflex waves which may produce much the same result by assisting the disturbance in certain places and acting against it in others. An intimate knowledge of the subsoil will explain such phenomena as these, but without it it is usually a very difficult matter to say why vibration is more sensible in one place or direction than another.

To those interested in the subject of vibration the example of the Manchester Square generating station of the Metropolitan Electric Supply Co. Ltd., London, is of value. The case may be termed classic, and it is often quoted to show the enormous difficulties which may arise in the operation of an engine plant in a central position. It shows further that even the most drastic and comprehensive remedies are at times inadequate to overcome vibration trouble. Manchester Square station, which is now shut down and converted into a sub-station of the St. Marylebone Borough Council Electricity Department, was assumed originally to stand upon solid ground, but when vibration trouble arose it was ascertained that about 10 ft. to 12 ft. below the floor of the engine-room there was a stratum of spongy clay or mud

which extended to a depth of 23 ft. resting on the solid London clay. The site was on or adjacent to the Tyburn Brook which originally ran across this part of London and can still be traced in certain parts of its course. The stratum of soft clay was subject to an influx of water after periods of heavy rain, and it was at such times that complaints of vibration were most frequent. The original foundation was laid on top of this stratum and consisted of a block of concrete measuring 88 ft. by 24 ft. by 7 ft. and weighing about 800 tons. It rested on a concrete floor with a layer of felt and lead intervening and was free of the walls all round. On this bed were installed ten 200 I.H.P. two line Willans central valve engines coupled direct to alternators and running at approximately 350 r.p.m. The stroke was 9 in., the cranks 180 deg. apart, the ratio of connecting rod to crank 4·77 to 1, and the weight of the reciprocating parts in each line 420 lb. For some years there appear to have been few complaints and it is stated on good authority that to a person standing on the foundation no vibration of any sort was perceptible, but apparently as the load on the station increased complaints became frequent, culminating in a searching inquiry by experts and an application for an injunction against the Company. In the meantime every effort had been made to improve conditions. At a cost of approximately £2,000 large cast-iron columns filled with concrete were placed under the original concrete bed, one between every two engines, and they extended for a depth of some 23 ft. right down to the solid clay. It was thought that this would overcome the difficulty, but vibration was still sensible to a considerable extent in neighbouring premises, and it was then seen that although the vertical disturbances had been stopped by these pillars the horizontal motion was still as active. It was evident that solid as the pillars were they yielded to a certain extent in a horizontal direction, moving

in the manner of an inverted pendulum. The bottom ends were fixed, but the top ends were to some extent free, and set up horizontal vibrations which were transmitted through the stratum of spongy clay. To remedy this, slanting struts were placed against the tops of the columns, but disturbances were still marked, and the evidence of the expert witnesses on this point is interesting. It tended to show that vibration was more marked at some distance from the works than it was in their immediate vicinity; an effect which has often been found in such cases and to be attributed to peculiarity of the soil. At certain houses at distances up to 100 yards from the station disturbances were at times very marked. Thus, the leaf of a palm was observed to vibrate incessantly with an ampliture varying from $\frac{1}{8}$ in. to $\frac{1}{2}$ in. and the floor of the room in which it stood was noticeably disturbed, especially in the centre. In an adjacent house at the same time the water in a small tub standing in a basement sink showed a periodic ripple.

A basement window was found to rattle with intermittences of about nine seconds, and windows in other houses were observed to chatter incessantly though fastened and tightly wedged. In order to make sure that certain of these disturbances were not due to extraneous causes such as street traffic or movement in the house the following simple piece of apparatus was constructed. A piece of glass was fixed in a frame, and a marble bullet was suspended by a thin wire close to it. The height of this bullet was adjustable, and when the position was found which best responded to the vibration of the house the ball rattled against the glass so long as vibration continued. It was unaffected by external causes of a temporary nature, such as a passing cart, because to set the bullet in motion repeated impulses coming in quick sequence were necessary. In the court proceedings it was proved beyond doubt that many of

the complaints of adjacent householders were well founded, and ultimately the Company removed the reciprocating engines and replaced them by steam turbines on the same foundations.

In 1895 Mr. Mark Robinson read a paper before the Institution of Electrical Engineers entitled "On the Recent Development of the Single-acting High Speed Engine for Central Station Work." In this paper he made some interesting comments on the Manchester Square case from which the following are extracts. Referring to the two line Willans engines with cranks at 180° apart he says. "There is an obvious couple which tends to set the engine rocking endways and to give rise to vibration. But it was incredible that the huge block of concrete could be tilted crossways by the couple between sets of pistons moving in lines only 2 ft. 3 in. apart. Besides, the effects produced and the known nature of the subsoil led to the belief that the block was not so much rocking as lifting up and down bodily, and acting like a pump upon the water-laden soil below (the complaints were most serious after heavy rain). It would have been easy to balance the 'couple' if that alone were the cause by dividing one of the lines of pistons into two, each of half the weight, but it was soon seen that it would effect no improvement in the station referred to, for on closely examining the matter mathematically Captain Sankey found that in the engines in question and broadly speaking in all vertical engines the tendency to rock endways by reason of an unbalanced couple was much less important than the tendency of the engine as a whole to move vertically up and down through a cause depending upon the obliquity of the connecting rod. Previous calculations had usually been addressed to balancing the couple as a practical solution of the whole vibration question, and though it was known that the obliquity of the connecting rod had an effect on the result it was believed to be disposed of by the

statement that ‘the slight and immaterial errors due to the finite length of the connecting and eccentric rods need not be considered.’ In the engines in question the two points of maximum piston velocity are of course above half stroke, hence the changes of piston velocity and therefore the inertia forces are greater in the upper half than in the lower half of the revolution. Without going into details it appeared that when each line of parts was near the top centre it exerted an upward pressure upon the engine of 3·54 tons, but when near the bottom centre it pressed downwards with only 2·31 tons. The couple is therefore not only a couple but a force, for the two members alternately exceed each other by about $1\frac{1}{4}$ ton twice per revolution. Twice per revolution there is a force of $1\frac{1}{4}$ tons trying to lift the engine; and twice per revolution this changes into a steady equal force acting downwards. A number of engines developing these unbalanced forces and synchronizing every few seconds were probably well calculated to produce the results complained of. At the same time Captain Sankey investigated the inertia forces in a three crank engine having the same revolutions, stroke and weights of parts, but with three cranks at 120° instead of two at 180°. Here the unbalanced vertical forces entirely disappeared, or rather, so nearly disappeared that they amounted to about 2 lb. only as against $1\frac{1}{4}$ tons. It was concluded that if three crank engines were substituted for the two crank engines the vibration difficulties would be ended, but the engineer of the lighting company naturally hesitated to adopt a remedy based chiefly upon calculations, for although such three crank engines were running elsewhere and with remarkable absence of vibration there was nothing to show with absolute certainty that the mathematical reason was the right one. He therefore shifted the engines to another station and put down steam turbines instead, feeling sure that they

would at least secure the object of getting rid of vibration."

Testing for Vibration

The methods employed in testing for vibration were for many years of a crude order. There is the familiar bowl of mercury, and the apparatus mentioned in connexion with the Manchester Square case, but these and such like simply indicate where vibration exists and give only the most approximate idea of its amplitude. Until the introduction by Messrs. Siemens Bros. & Co., Ltd., of an instrument termed the Vibragraph no practical method existed for measuring and recording vibration in definite units. The want of such exact expression has always been felt, particularly in legal cases where, it is well known, the evidence of witnesses though given in good faith is often unreliable and inconclusive owing to widely varying susceptibilities.

The instrument in question is readily portable, being convenient in size and weighing about 24 lb. The essential part is a cup of mercury which is provided with a floating mirror so pivoted as to avoid lateral movement. A small electric glow lamp is placed outside the case, throwing its light on to the mirror through an aperture in the top, and this beam of light is reflected upward to a slide holding photographic paper, or alternatively to a screen if direct visual observation be desired. The ripples in the mercury caused by vibration give an angular movement to the mirror, and the beam of light records on the sensitized paper a straight line if the vibration is in one plane only or a complex figure if it be in planes at different angles as is usually the case in practice. The actual movements are magnified at least a hundredfold. The instrument has three different mercury cups each suitable for recording respectively strong (say 0·3 mm.) medium (say

0·08 mm.) and small (say 0·02 mm.) vibrations. Each cup has its own constants, and is supplied with a set of calibration curves which allow of the actual movement of the vibrating body being determined from the photographic record in fractions of inches or millimetres.

CHAPTER IX

VIBRATION.—METHODS OF ISOLATING MACHINERY

Isolating Substances and Methods

For the purpose of isolating foundations from the surrounding soil and absorbing vibration and shock, a considerable variety of substances and methods have been employed.

In building practice it is a well-known expedient to place layers of ordinary felt and sheet lead under foundations, and from this no doubt arose the similar custom in connexion with machinery. In brick foundations such layers have been used between the lower courses, imparting, at any rate for a time, a certain amount of resiliency. Another system which may suffice for light machinery is to place under the bedplate and on top of the foundation a shallow pan filled with hair felt, the function of the pan being to prevent the felt from expanding laterally under the weight. This same expedient becomes necessary where asphalt is used. It is stated to give good results if over ½ inch thick, but it appears doubtful if such an insulator can be of much service in work of any size or under bad conditions. Slight elasticity may be secured by placing timbers of pine, beech and elm, or raw hide soaked in oil, under the bedplate, but here again it is impossible to regard such a method as a solution to anything but the simplest case. Timber has often been applied to a

steam hammer in the manner shown in Fig. 32, and under many conditions it is effective, but the problem of the power hammer is a different one to that of an engine or machine which sets up continuous vibrations of a comparatively small amplitude, and a method which may be suitable in the one case will in all probability fail entirely in the other. Until a fairly recent date, an engineer wishing to isolate a machine had no choice beyond such comparatively rough-and-ready methods as the above. Sometimes they were satisfactory, but there is no doubt that a good deal of money has been wasted upon expedients of this class. Effective isolation which will retain

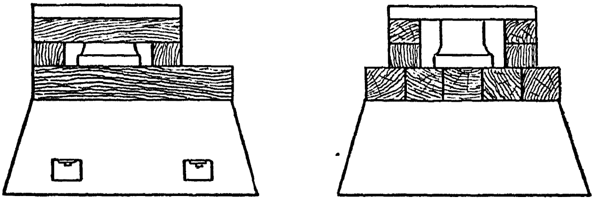


FIG. 32.—Concrete and Timber Foundation for Steam Hammer.

its full efficiency for an indefinite period is not easily secured, and the best course is certainly to take advantage of the experience of one or other of the firms who make a speciality of supplying substances of a tried and suitable class. The following systems of isolation are among the best known, and each represents a particular line of practice.

HARBURG AND VIENNA RUBBER CO.'S SYSTEM (Vakuum-Fundament von Rügen.)

In this system rubber sheet of a special quality is inserted under the foundation or footings of the machinery. It is only advised for heavy plant, as the

results are not so satisfactory with light machinery or where the centre of gravity is high. In applying this system the chief essential is that the surfaces between which the rubber sheet is placed should be perfectly smooth, in order that an even pressure may be assured, as it is only under such circumstances that proper adhesion between the rubber and the surfaces can be secured. A thickness of from 3 mm. to 4 mm. is recommended for machinery weighing up to 3 tons, but over this weight, or where vibration is excessive, a heavier sheet should be used. The cost of this sheet ranges approximately from 11*s*. 3*d*. per lb. in 3 to 6 mm. thicknesses, to 20*s*. per lb. where the thickness exceeds 9 mm.

Prache System

The inventor of this system of isolation is M. Prache, whose work on the subject of vibration is well known. The system has been used to a considerable extent both in Great Britain and abroad, and has been applied to many classes of machinery including heavy printing presses, steam engines and steam turbines. An example of installation in the latter case will be of interest. The size of the turbo-generator is 2,000 KW., and it is bolted to a slab of reinforced concrete 2 ft. thick. This slab rests upon a number of circular indiarubber stools which when under compression are 4 in. in diameter and 3 in. high, and these stools in turn rest upon the ordinary foundation. To enable the rubber blocks to be readily inspected or renewed if necessary a trench is provided all round the concrete slab, which latter is of course entirely free from the engine room floor or walls. Under the Prache system renewal of the blocks is a matter of very infrequent occurrence, but when this becomes necessary is is provided for in the following way. Each block is held in a form of jack by means of which further compression than

that due to the weight of the slab and machine can be put upon it. These jacks are accessible from the trench, and when it is required to remove a block it is only necessary to screw down the jack slightly and slide it and the block out from beneath the slab. The rubber employed is of a special quality and is specially treated in order to lengthen its useful life.

Korfund System

This system, which has been in use for some considerable time and is employed in a large number of installations both at home and abroad, consists of plates built up of single cork strips, specially selected, treated and impregnated. These strips are securely bound together by an iron frame having iron internal struts which separate the plate into sections, but not being level with its surface do not carry any of the weight. The cork strips are natural and not built up of waste, and the impregnation is stated to increase elasticity and minimize decay. Plates are made of the same area as the foundation and in the shape of the plan of the machine. It is recommended where the plates go directly under the footings of the machine as in printing presses, etc., that strong planks or plates should be placed between in order to distribute the weight as far as possible over the cork plates. In the case of concrete foundations a clear space is left round the block in order to isolate it from the surrounding soil, but where a belt drive is used the lateral pull is met by inserting a plate on the driving side of the foundation. A considerable advantage is claimed for this insulator over cork plates built up of small pieces and a binding material. The latter fills up the pores of the cork, destroying its resiliency, with the result that under heavy compression whatever slight elasticity it may have had practically speaking vanishes. With a plate built up on such lines there is in addition the risk of disintegration and ultimate

collapse. Cork has also been used in the form of strips fixed to planks or embedded in asphalt, but it is stated that such devices have not met with much success owing partly to their becoming displaced under the irregular compression produced by heavy engines. Korfund plates are made in two thicknesses, viz. $1\frac{1}{2}$ in. and $2\frac{3}{8}$ in., and the cost is respectively 5*s*. 6*d*. and 7*s*. per square foot.

Mascolite System

In this system, which was introduced by Messrs. Mitchells, Ashworth, Stansfield & Co., Ltd., the particular feature is a special proofed felt used either alone or in combination with cork and rubber. As a system it is one of the most comprehensive, being applicable in one form or another to any case of noise or vibration. The felt employed is a special mixture of fibres which has been selected after lengthy trials as the best sound and vibration absorber. It is treated in such a manner that it will stand climatic changes, dampness and the attacks of insects, and the tests given in Table XXV tend to substantiate the important claim that it will not take a permanent set under heavy loads. These foundation felts are made in three types of which the simplest is "Mascolite P," a plain proofed felt manufactured in thicknesses of from $\frac{1}{8}$ in. to 1 in. It is suitable for small foundations or for cases where vibration is not very bad and costs from 8*d*. to 3*s*. 8*d*. per square foot according to thickness. The second type, "Mascolite BU", is built up of alternate layers of the same felt and thin layers of cork. It is supplied in thicknesses of from $\frac{1}{4}$ in. to $1\frac{1}{4}$ in. or more if desired, and ranges in price from 1*s*. 3*d*. to 6*s*. per square foot. It is naturally a better anti-sound and vibration pad than the single thickness felts and is largely used for engine foundations. "Mascolite IR" is the third type. It can be made

either with the special felt in layers alternately with vulcanized rubber sheet of any thickness or with the built up felt BU with alternate rubber layers. Thus, a pad built up on these lines will contain in the latter case layers of felt, cork, felt, rubber, felt and so on. Both the rubber and felt can be varied in thickness to conform to any specification, but the usual thickness of the pad is 1 in. and that of the rubber sheet $\frac{5}{32}$ in. The cost of the felt and rubber combination is 12*s.* 8*d.* per square foot and that of the felt, cork and rubber pad 13*s.* 8*d.* per square foot. All these types may be extra-waterproofed for use in very wet or exposed positions and this will have no effect upon their resiliency.

Experience has shown that ordinary felt such as is sometimes advised for foundation isolation takes a permanent set under heavy loads and therefore loses a considerable part of its resiliency. As stated, it is claimed for "Mascolite" felt that there is no permanent set under the worst conditions obtaining in practice, and the following independent tests made by Messrs. David Kirkaldy & Son are advanced in support of this contention.

In each class of felt three samples were tested and the above are the mean results. Depression measurements were taken at a number of intermediate stresses as well as those given, but from considerations of space they are not included. It may be mentioned that the pieces actually tested differ in no wise in appearance from new felt in spite of the fact that the stresses were considerably higher than those the felt would be called to bear under any foundation. As was shown in Chapter III these are generally in the neighbourhood of 1,000 or 2,000 lb. per square foot. It is interesting to note that the percentage set after twenty-four hours release is lowest in the IR grade which incorporates rubber, a fact which shows its superiority for heavy work.

There are certain points in the installation of these

TABLE XXV

RESULTS OF EXPERIMENTS TO ASCERTAIN THE RESISTANCE TO A GRADUALLY INCREASING THRUSTING STRESS OF NINE PIECES OF "MASCOLITE" FOUNDATION FELT

Description.	Weight per Sq. Ft.	Dimensions.		Mean Thickness.	Stress in lbs. per Sq. Ft.				Remarks.
		Size.	Area.		20,000.	100,000.	200,000.	300,000.	
					Depression, Inch, at above.				
	Lbs.	Inches.	Sq. in.	Ins.					Load removed.
Mascolite P. Thickness ½ in.	1·033	6·02×6·02	36·24	·50	·041	·204	·267	·299 Set ·21	Set after 24 hours release ·10 in.
Mascolite IR Thickness $\frac{15}{16}$ in. 2 layers rubber $\frac{5}{32}$ in.	5·202	6·02×6·01	36·20	·96	·021	·074	·147	·205 Set ·065	Set after 24 hours release ·03 in.
Mascolite BU. Thickness 1 in. 3 layers cork in each piece.	2·684	6·02×6·01	36·20	1·02	·047	·243	·375	·458 Set ·29	Set after 24 hours release ·16 in.

felts which call for notice. Fig. 33 shows a good arrangement in which the concrete foundation is divided into two parts with the felt placed between them. The concrete is shovelled in on top of the felt, and as the latter is free from oil or grease it adheres strongly to the concrete. The foundation bolts it will be noticed do not extend into the lower bed, as by so doing they would conduct vibration past the felt and to a great extent nullify its effectiveness. The sides and ends of the foundation should also be kept free from the surrounding soil by an air space, which, if preferred, may be filled in with felt. Sand and sawdust have often been recommended for this purpose, but while they are effective when new they naturally tend to harden in course of time and are then capable of transmitting vibration. An alternative plan to that shown in Fig 33 is to place the isolating medium directly under the engine, using by preference the built up felt. In this case it is necessary to bush all bolt holes in the bedplate with strips of $\frac{1}{8}$ in. felt bent into cylindrical form, and also to insert $\frac{1}{4}$ in. felt washers under the bolt heads so that the machine may be completely isolated from the ground.

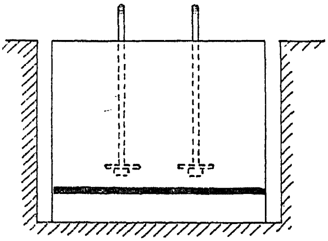


Fig. 33.—Method of Applying Felt Insulation.

Fig. 34 is a section of a factory showing in an exaggerated manner by means of the heavy black lines the various places where felt may be used to deaden vibration. The main engine and dynamo are treated in the manner already described. The steam hammer, however, is isolated at both the top and bottom of its foundation, and a layer of felt is also placed in the joint of its frame. The wall brackets

and hangers and each machine are isolated in the ordinary way, and the lift motor is similarly treated with the addition of pads under the ends of the supporting beams. These pads are also used under the floors at the points where they are supported.

Spring and Flexible Mountings

The mounting of machinery on springs with a view

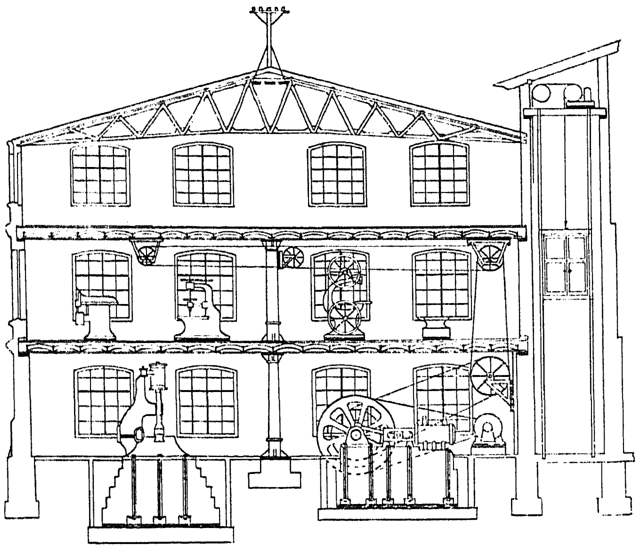


Fig. 34.—Section of Factory Equipped throughout with Felt Vibration Insulation.

to damping vibration is by no means usual, but it has been done, and in certain cases with success. The proposition does not commend itself to the average engineer who is prone to look upon rigidity of fixing as a *sine qua non* with practically all machines, but there can be no doubt that some cases can ad-

vantageously be treated in this manner, and it is by no means certain that a more general adoption of the principle would be a mistake. In 1897 Mr. James Swinburne read a paper before the Institution of Civil Engineers, entitled "Should Generating Plant be Mounted on Springs?" which subject is, as he said, really part of a larger question, "Should Moving Machinery be Mounted on Springs?" The paper is of interest to students of the subject but at the same time somewhat inconclusive, as although the author advanced theoretical reasons in favour of the principle, he touched only very slightly upon the more interesting practical side. In a few words, the contention of those who lean to flexible as opposed to rigid bedding is that no engine or machine is perfectly balanced and each will therefore tend to move its bedplate and set up vibration. This being the case it is reasoned, Why not let it have free play so far as steam and other pipe connexions will admit? Such a course should obviate all vibration troubles and, it is stated, would cause the engine to wear less as all parts are subject to smaller strains. It is difficult to answer this question because (always assuming its practicability from the point of view of pipe or other connexions) there seems no valid reason why a machine should not be allowed at any rate modified movement. For instance, where the tendency is to rock endways the foundation might be given a convex base and bedded in dry sand which would permit the whole to oscillate slightly. Further, it has been suggested that a tendency to horizontal vibration might be accommodated by mounting the concrete block on rollers which would allow it to move backward and forward with the engine impulses, and another proposal consists of suspension of the whole engine and bed by long rods with freedom to swing laterally. Whether such schemes are practicable or not it is difficult to say. It would be unwise to condemn them *en bloc* because it is possible that under

certain and probably unusual conditions they might be successful. Failures are on record, but almost entirely in the field of comparatively large steam and gas plant; on the other hand there is plenty of evid-

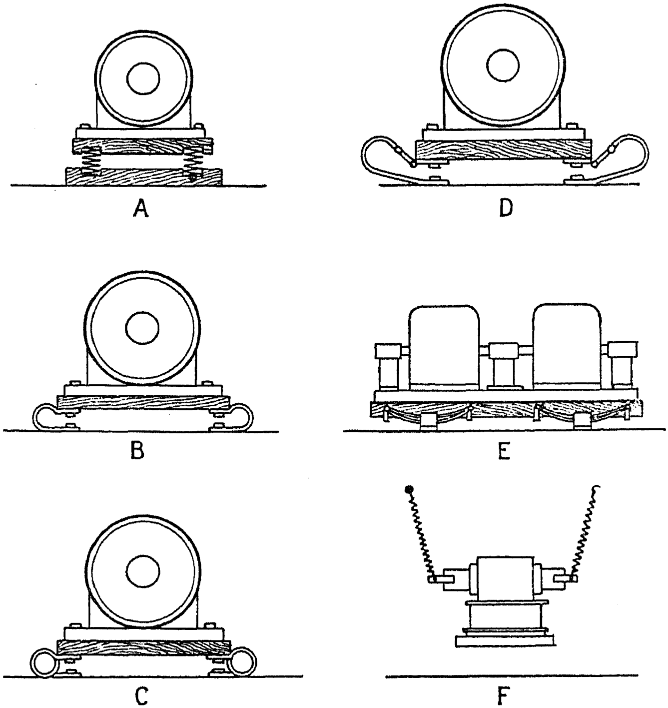


FIG. 35.—Spring Mountings for Electric Motors.

ence to the effect that the flexible mounting of the electric motor (preferably through the agency of springs) is thoroughly practicable. Some years ago Mr. Sherard Cowper-Coles, writing in the *Electrical Review*, gave some interesting instances of the mount-

ing of motors in this manner, and the principles he outlined (all of which have been in practical use) are shown in Fig. 35. Method A was found very satisfactory. The motor was of $1\frac{1}{2}$ H.P. running at a speed of 1,450 r.p.m., and was employed for driving light machinery in a room over some residential flats on a badly constructed floor. It was not bolted down, but a heavy weight was used to counteract the pull of the belt, and lateral movement was prevented by the ends of the springs being sunk into holes in the wooden frames. Methods B, C, D, and E have been employed for heavier motors. In the first the springs are of a simple U shape with their ends fixed respectively to the floor and the wooden frame. In the second the springs are coiled, and this form should be suitable for a heavier motor. In D the machine is hung in much the same manner as a carriage body, and in E, axle springs of a bow shape are employed. The latter is probably the most satisfactory mechanical job, and it should be possible to support comparatively heavy motors in this way with considerable advantage. The method shown at F, in which the motor is suspended by helical springs, is of course only suitable for small motor-transformers, but it is worthy of note as these machines are at times troublesome by reason of their noise and of vibration set up through want of proper balance. In putting such ideas into practice it is of course essential to take into account the pull on the belt and the angle of drive, both of which will have a material effect on the practicability of the scheme. Such points can hardly be theorized upon and it would probably be necessary to conduct several experiments before arriving at the strength and form of spring most suitable for the conditions. As a rule the built up coach spring shown at E, Fig. 35, is preferable to anything in the nature of a helix. The latter possess no damping action beyond that arising from friction in the metal and are consequently apt to be too sensitive

and unstable. The laminated plate spring overcomes this difficulty by means of the friction between the plates or leaves of which it is built. The pressure between the leaves is great, and the sliding action sets up a considerable amount of friction which to a certain extent absorbs shock and retards the action of the springs, thereby giving increased stability without excessive rigidity. It is necessary to build bow springs up in this way because a solid spring of one piece strong enough for the load would be far too rigid to deflect and absorb vibration. The strength of laminated springs varies with the number of leaves; the size of the smallest leaf; the width of the material; the square of its thickness; and the nature of the material. According to D. K. Clark the weight which may be safely put on a spring of this type is ascertainable by the following formula—

$$\text{Safe load in tons} = \frac{B\ T^2\ N}{C\ S}$$

where B = width of plates in inches.
,, T = thickness of plates in $\frac{1}{16}$th inch.
,, N = number of plates in spring.
,, S = span of spring in inches.
,, C = constant = 11·3 up to 15.

This formula is used in the design of wheel springs, but it should be equally applicable to the case in question.

The following formulae will be found reliable for the design of helical springs of round, square and rectangular section steel respectively.

Round section.

$$\text{Total deflection of spring in inches} = \frac{WD^3}{Cd^4} \times n.$$

Square section.

$$\text{Total deflection of spring in inches} = \frac{WD^3}{Cs^4} \times n.$$

Rectangular section.

Total deflection of spring in inches =

$$\frac{WD^3 (b^2 + h^2)}{Cb^3 h^3} \times n$$

Where :—

C = a constant as follows :—

For round section,	1,442,000	to 1,750,000
,, square ,,	2,000,000	to 2,500,000
,, rectangular ,,	4,000,000	to 5,000,000

W = working load in direction of axis in lbs.
D = diameter of coil, centre to centre of section, in in.
d = diameter of section for round section steel, in in.
s = side ,, ,, ,, square ,, ,, ,,
b = breadth ,, ,, ,, rectangular ,, ,, ,,
h = height ,, ,, ,, ,, ,, ,, ,,
n = number of effective coils in spring.

In the case of volute springs,

Total deflection of spring in inches =

$$\frac{W(D_1^4 - D_2^4)}{Cbh^3 (D_1 - D_2)} \times n,$$

The notation is as before excepting as follows :—

D_1 = maximum diameter of coil, centre to centre of section, in inches.

D_2 = minimum diameter of coil, centre to centre of section, in inches.

C = a constant ranging from 19,014,000 to 23,767,000.

CHAPTER X

THE FIXING OF ELECTRIC MOTORS

ONE of the chief merits of the electric motor is its adaptability to different circumstances, and this undoubtedly accounts for much of its popularity. Position is of little moment to a suitable type of motor, and the fact that it may be as readily fixed on the walls or ceiling as on the floor is alone sufficient in many cases to give it preference over any other form of motive power. Since foundations in the usual sense of the word are costly, and occupy what is often valuable space, they are best dispensed with if possible, and with the electric motor this can frequently be done, especially in the smaller sizes which will not throw too great a strain upon the building structure when fastened direct to it. In this respect, however, for a given horse power much will depend upon the speed of the motor and therefore the pull on the belt, and also the angle which the latter makes with the part of the structure to which the motor is attached. With a building of ordinary strength these are not points of importance, but they should be recognized and allowed for where there is evidence of weakness. Whether it is preferable to fix to floor, wall, ceiling or column depends of course upon the circumstances of the case. If space is of no consideration the floor is preferable for the obvious reason that the machine is more get-at-able, but with a good motor the point is not an important one. On the other hand, it must be remembered that a motor fixed to a wall, ceiling

or column is more apt to give rise to trouble with vibration and noise. Further, in such a position it may interfere with travelling cranes, etc., and it is also not always possible to secure the requisite length of drive unless a chain be employed. These considerations together with the effect on belting and shafting and the general lay out of the machinery require careful thinking out and weighing one against the other.

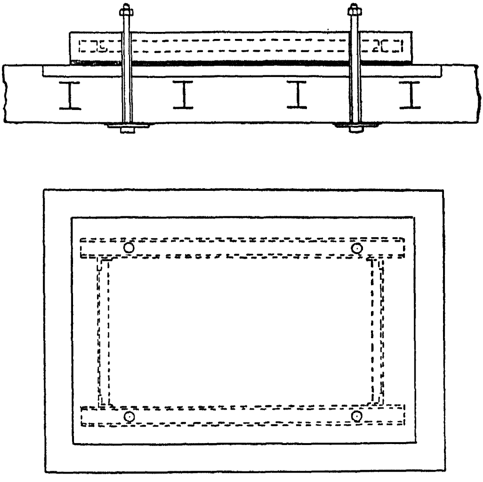


FIG. 36.—Isolated Foundation on Concrete Floor.

FLOOR FIXING

The design of ordinary concrete or brick foundations for motors has been dealt with in Chapter III. It remains here only to treat of cases which are not covered by the block foundation of the usual type. Prominent among these is the installation of a motor or a self-contained motor driven machine on a concrete and girder floor, which if a very sound construction is desired may with advantage be carried

out on the lines illustrated in Fig. 36. In this case the floor is 1 ft. thick and its surface is remade as shown with 3 to 1 granolithic concrete for a depth of about 2 in. Next comes a 1 in. layer of special proofed felt to absorb vibration, and its edges are treated with three coats of paint as a preservative. Finally, a 6 in. concrete bed is laid on top of the felt, 4 in. by 2 in. channel iron and 2 in. by 2 in. angle iron being incorporated in it as shown. The bolts, which are 1 in. in diameter, run through clearing holes in the concrete and channel iron which are bushed with $\frac{1}{8}$ in. felt to prevent the communication of vibration. The anchor plates are 9 in. by 9 in. and have a $\frac{1}{4}$ in. pad of felt under them for the same purpose. This is a very sound form of construction which would be quite suitable for a small gas engine or any reciprocating machine. As a rule an electric motor will not need channel or angle iron reinforcement or felt insulation unless it is of large size or badly out of balance. Generally, a motor or any self-contained electrical machine may be fixed to such a floor direct without anything in the nature of a foundation. A much simpler but effective method of holding down a small motor without the aid of proper foundations is illustrated in Fig. 37. Four pieces of timber 9 in. by 3 in. or thereabout, with their edges chamfered, are laid in the manner shown. They may be bolted together at the corner if desired, or the coach screws by which the motor is held down may be run through them if the pitch of the holes in the base plate is suitable. When in position and levelled the timbers are surrounded with concrete up to the surface of the upper

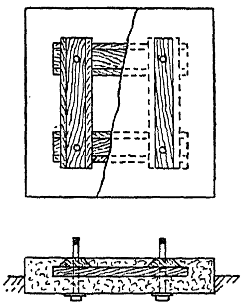


FIG. 37.—Light Concrete and Timber Foundation.

ones and this completes the job. The method will be found very suitable for temporary work as it is particularly cheap; at the same time it is effective and quite satisfactory for the permanent installation of any small self-contained unit.

WALL FIXING

A motor may be fixed to a wall in two ways; either direct with its base plate against the wall, or on a properly constructed bracket. In the former case it will lie at right angles to its normal position, but in the latter its proper vertical position will be retained. Generally speaking, it is preferred to fix direct to the wall as this is the stronger and at the same time cheaper construction, but small motors are often placed on brackets which if lightly made are easily and cheaply fixed. Fig. 38 shows the manner of securing to a brick wall by means of bolts running through the base plate and brickwork. The anchor plates on the outside of the wall should be of ample size in order to distribute the load, and the surface of the wall in contact with the base of the motor should be as smooth as possible to give it a good seating. If unduly rough a layer of sheet lead, felt or pine planks inserted between the two will improve the bed. Small motors may be fixed to a substantial brick wall by Lewis or rag bolts grouted in, but for a heavy machine the bolts should certainly extend right through the wall. It should be unnecessary to draw attention to the fact that a motor fixed in this position with its base plate in the vertical plane will probably require some alteration to its lubricating gear. It is, however, by no means unusual for this to be overlooked until the motor is

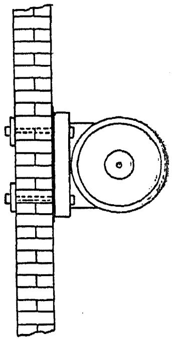


FIG. 38.—Motor fixed to Brick Wall.

erected and ready for work. Some machines are specially built for running in this position, but if the ordinary type has been supplied it is generally only necessary to remove the end frames which carry the bearings and rotate them through an angle of 90°.

If the wall to which the motor is to be fixed is of wood, as is often the case in factories, the method shown in Fig 39 is usual. Two stout wooden battens are bolted to the beams in the manner indicated, and to these the motor base is fixed with good sized washers under the heads of the bolts. The use of coach screws is not advisable unless the machine is of the smallest size, and discretion must of course be used in attaching any motor to a wooden partition wall which may be quite unsuited to bear the strain. In such a case a way out of the difficulty is to erect a stout and well braced wooden frame against the wall and fix the motor to this. The frame should be properly tied to the beams of the floor and the ceiling, but left quite free of the partition wall unless the latter is strong enough to bear some of the strain.

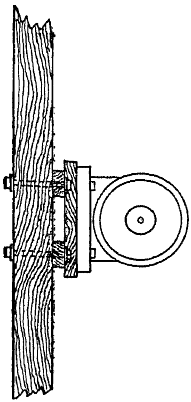
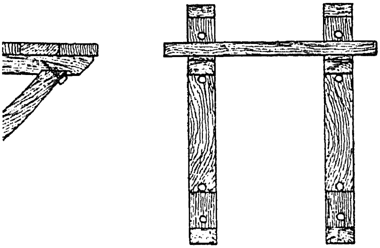


FIG. 39.—Motor fixed to Timber Wall.

Bracket supports may be made either of wood, cast iron or steel plate and angle iron. It is unnecessary to touch upon the cast-iron bracket which is a standard article obtainable anywhere, but the two remaining types will have to be made specially and therefore call for some discussion. Fig. 40 shows the method of construction and fixing of a wooden bracket suitable for bolting to a brick wall and carrying a motor of 10–20 H.P. or so. It is built of 6 in. × 8 in. timber, measures 8 ft. over all vertically and 4 ft. 6 in. between centres of the wall timbers. The shelf is

ɔards and is approximately 6 in. wide
·ep. Eight $\frac{3}{4}$ in. bolts with substantial



-Timber Wall Bracket for Motor.

he heads run through the wall at 2 ft.
nd the diagonal struts, of which the
into the other two members of the
ıred by coach screws. Such a bracket
wood is very reliable, and the same
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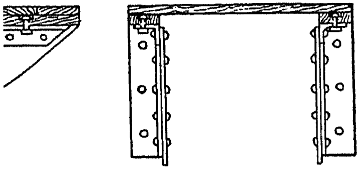
size. The best form of wall bracket
that shown in Fig. 41. The steel



—Steel Wall Bracket for Motor.

ıders it absolutely reliable and it is
ne inexpensive. Fixing to the wall

would be carried out on the lines shown in Fig. 40, and a similar wooden flooring or steel plate to support the motor should be provided. In the case of a heavy machine it is desirable to place vertical steel angle struts between the end of the bracket and the ground, or if preferred, they may slope at an angle to the wall, the bottom ends being fixed to the latter by substantial bolts.

Column Fixing

In the fixing of motors to columns there are many courses open, the weight of the motor and the nature of the column influencing the choice. In the simplest case, namely that of a wooden column, a small motor may be fitted up in the manner shown in Fig. 42 by means of a wooden bracket and coach screws. As a rule, wooden beams are only suitable to carry quite small powers, and for such, a bracket of this type will suffice. A larger motor may be supported in the way illustrated in Fig. 43. This arrangement will take

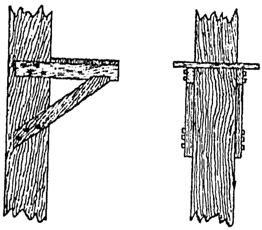


Fig. 42.—Wooden Column Bracket for Motor.

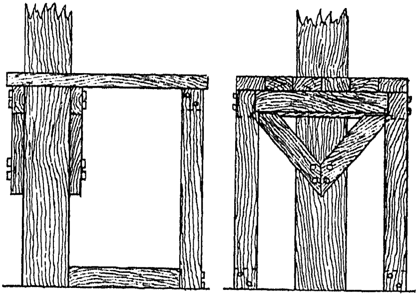


Fig. 43.—Timber Column Bracket for Motor, supported from Floor.

a considerable amount of weight and strain off the column, but the shelf should be kept as low as possible in the interests of stability. If necessary to fix at a good height the front legs should be braced diagonally and tied to the column at the foot. In respect of the size of motor, reinforced concrete columns may be placed in the same category as timber. It is difficult to obtain a fixing to concrete columns, and for this reason alone it is inadvisable to attempt to instal anything but a very small machine on them. A very good method is that illustrated in Fig. 44. Two wrought iron $\frac{3}{4}$ in. bolts are bent into U form to lie in grooves cut in three sides of the column. If very little weight is to be put on them they need only encircle it without being sunk in grooves, but the provision of the latter at the back of the column at least, if not on all three sides, is the only certain means of preventing slip. The ends of these bolts are passed through stout battens and the mounting board of the motor as shown, and the nuts are then screwed up, tightening the whole securely to the column. If it is preferred that the motor should stand in its normal vertical position it is only necessary to fix a suitable iron or wooden bracket to the battens.

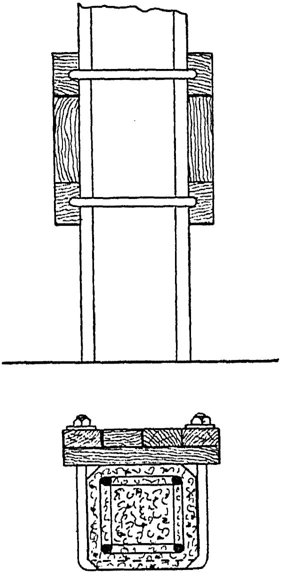


FIG. 44.—Method of obtaining Fixing to Ferro-concrete Column.

Fixing to structural steel columns is easily carried out by means of steel brackets built up on the lines

shown in Fig. 45. Steel plate and angles are used throughout, the whole being riveted together and the bracket attached to the column by bolts. This is a very usual method of fixing and is inexpensive, particularly if a fair number of brackets are required. It will, however, scarcely suffice for large motors which

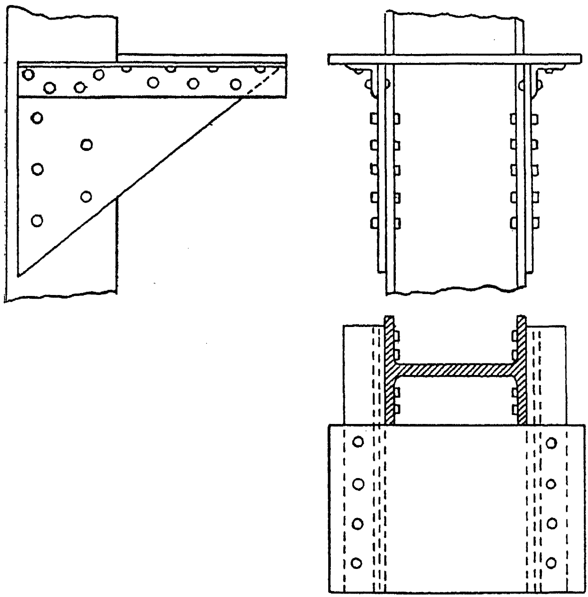


FIG. 45.—Steel Bracket for Structural Steel Column.

if possible are better mounted in the manner shown in Fig. 46. Here, channel irons or I beams are fixed by means of heavy cast-iron brackets between two adjacent columns, and the motor rests on these stringers with or without a platform according to the exigences of the case. The best method of securing

the motor is to bed it direct on the stringers and clamp. it down to angle irons running across the stringers underneath, but this is not always possible as the motor base may be too wide and overhang the stringers on each side. In such a case the pull of the bolts would tend to spring and possibly crack the baseplate, and at the best the fixing would not

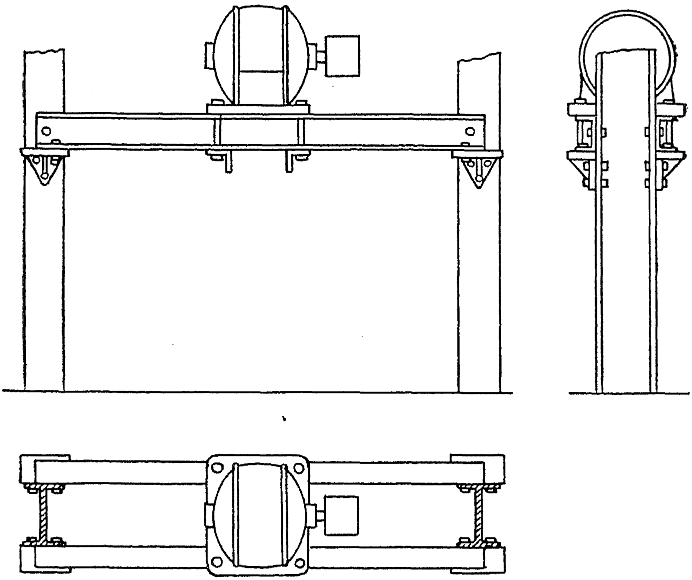


FIG. 46.—Method of supporting Motor between Two Steel Columns.

be good; hence, a stout steel plate platform must be fixed to the stringers and the motor bolted to this. Obviously, this method of securing to columns would sometimes require and is capable of wide variation. For instance, if the span of the stringers is too great for proper rigidity it would be necessary to reinforce

them by lattice work or struts. Also, there are many different means of fixing the motor to the stringers, and the materials that happen to be handy would no doubt influence this.

CEILING FIXING

The methods employed in wall fixing are often applicable to ceiling fixing when suitably modified.

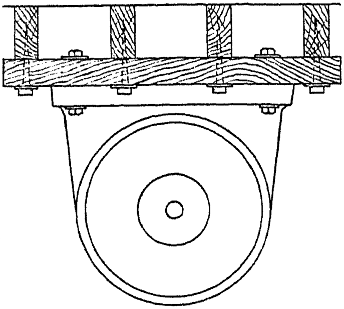


FIG. 47.—Method of suspending Motor from Wooden Rafters.

If the one position is structurally as suitable and as strong as the other the procedure will in many cases be identical, with the exception that the motor end frames must be rotated through an angle of 180° instead of 90°, as is the case where the machine is fixed at right angles to the wall. The accompanying illustrations show certain methods which have been specially designed for ceiling fixing, but obviously they might also be applied to obtain a fixing to vertical beams or girders. Fig.

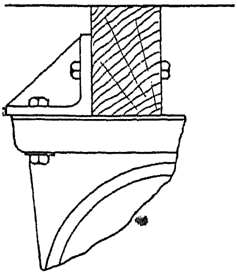


FIG. 48.—Method of Attachment to Wooden Rafter by means of Iron Bracket.

47 is a suitable arrangement for the suspension of a small motor from wooden rafters, but as it is dependent upon coach screws it should only be used for light work and preferably with a horizontal drive. Fig. 48, in which an iron bracket is bolted to the beam is a stronger construction and will carry any load the rafters will safely bear.

In Fig. 49 the motor is suspended from the rafters in a cradle constructed of stout timbers held together by bolts and not coach screws. The motor is preferably fixed down in the manner shown, and in this case the outer planks of the floor do not require separate fixing. The centre plank or planks might be held by spike nails or coach screws with

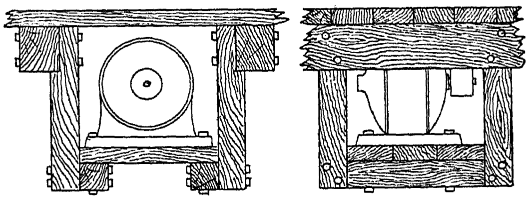


FIG. 49.—Timber Cradle for Suspension of Motor from Rafters.

counter-sunk heads. A cradle of this nature should not hang lower than is absolutely necessary, and the method is really only suitable where the motor can be placed high up against the ceiling. The lower the motor the greater will be its leverage and the strain on the cradle, which will be less rigid and more liable to vibration. The same principle may, of course, be carried out in structural steel work which will make a better and more sightly job.

The method illustrated in Fig. 50 is a handy one for girder work, being particularly useful when an extension of the flange is desired. It necessitates the use of a special bracket which, however, is of a

standard shape and can be supplied by most firms specializing in millwork and power transmission accessories. It is not always an easy matter to obtain a fixing to a box girder and the arrangement shown in Fig. 51 may be useful. A substantial plate (also a standard article) is held to the lower flange of the girder by means of hook bolts, and it is essential that it should be a good fit so that there should be no risk of working loose. This plate is drilled in any desired place to receive the motor holding-down bolts which are placed in position before the plate is fixed.

The above represent a few of the numerous accessories which are supplied for this class of work.

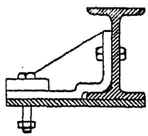


Fig. 50.—Extension of Girder Flange to obtain Fixing.

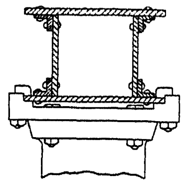


Fig. 51.—Method of Obtaining Fixing to Box Girder.

Almost every condition of structural steel work has been anticipated, and it should only be necessary to look through the catalogues of a few machinery merchants to find a class of fitting which will meet ordinary requirements.

Alteration of Position

It may occasionally happen that the position of a motor or machine mounted on a concrete foundation has for one reason or another to be altered slightly; not enough, perhaps, to necessitate a new foundation, but sufficiently to leave only a portion of the machine on the original one. An obvious course is to extend

the foundation in the requisite direction, but the method shown in Fig. 52 is generally simpler and cheaper and in certain circumstances may suffice. In the typical case illustrated the machine was a small winch which it was desired to place at an angle with its original position and to move some two feet to the side. The $\frac{3}{4}$ in. holding-down bolts were built solid in the concrete foundation, which, as shown, was sur-

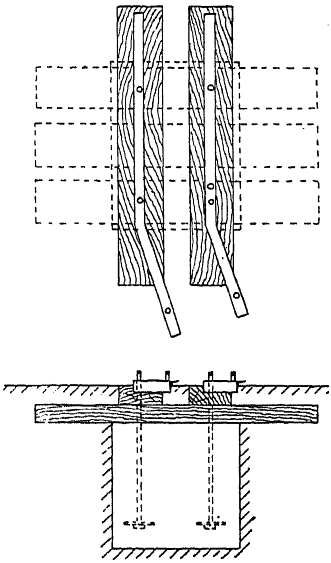


FIG. 52.—Method of Extending Holding-down Arrangements to suit Alteration of Position.

mounted by 14 in. × 6 in. sleepers in two layers at right angles to one another and surrounded by made ground. The four bolts extended right through the sleepers and held the winch bedded to them. The upper layer of sleepers was removed, and two pieces of 3 in. × 3 in. steel angle bent into the required shape

were secured to the original holding-down bolts in such a manner that their ends overhung the foundation and afforded a fixing for one end of the winch when placed in its new position. The other end of the winch was fixed to the angle iron by bolts suitably spaced. The vertical side of the angle iron was bedded in a groove cut in the sleepers in order to take the pull which was in a horizontal direction as the tackle ran through a snatch block fixed to the ground.

This principle with details altered to suit the circumstances could be employed in many cases, particularly where the machine is self-contained, that is to say, not connected by belt or gearing to another machine. It is useful for hurried jobs where it would be impossible to leave the machine out of commission long enough for a new concrete bed to set properly. Under certain conditions the leverage the machine would have on the free ends of the angle iron would render the arrangement illustrated unsafe, and owing to its lack of rigidity trouble might also be experienced with vibration. These two difficulties could be overcome by anchoring the ends of the angle iron to an adjacent wall or other stable object. Failing this, a comparatively small concrete bed to which the ends could be anchored would suffice.

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